NEW NUCLEAR BINDING ENERGIES AND THEIR ANALYSIS

S.I. Sukhoruchkin , D.S. Sukhoruchkin

B.P. Konstantinov Petersburg Nuclear Physics Institute 188300 Gatchina

1. General remarks

Nuclear data files are collection of results of measurements of the properties of the material used in every-days scientific activity and practical applications. Three data files, namely, neutron resonance parameter file NRF [1], the file of nuclear excitations CRF [2] and the file of nuclear masses MDF [3] are collected in PNPI. They contain results of the immense production of data needed for practical application and the development of nuclear science started by E. Rutherford and N. Bohr. Recent development of high-energy physics resulted in data contained in Compilations by Particle Data Group [4] and CODATA [5]. These PDG and CODATA Compilations and above mentioned nuclear data files (NRF, CRF, MDF) provide the material for combined analysis of all existing information for the further development of the theory of all particle interactions (the Standard Model, SM), which would include the gravitation and the origin of the dark matter. Y. Nambu suggested that data on particle masses could provide an important information for further SM-development. Involvement of nucleon masses into correlations with masses of other particles, including such fundamental particles as leptons, the pion and masses of vector and scalar fields [6-15] allowed a combined consideration of data in all these data files (PDG, NRF, CRF, MDF). We start with CODATA relations for the electron and nucleon masses:

$$m_n = 115 \cdot 16 m_e - m_e - \delta m_N/8 \qquad\qquad m_p = 115 \cdot 16 m_e - m_e - 9\delta m_N/8. \quad (1)$$

Here the shift in the neutron mass (relative to the integer number of m_e) δm_n=161.65 keV is exactly rational (1:8.000) to the nucleon mass splitting δm_N. We have found that fine structure with the period 161 keV and close to it but not coincident the period $m_e/3$=170.3 keV are the same as earlier observed fine structures in nuclear data. Recent analysis of data for nuclei with Z,N=20,28 confirmed the fact that values $\delta m_N/2$=646 keV and $\delta m_N/4$=323 keV (k=4 and k=2 of the period $\delta m_N/8$=161 keV) and stable intervals 170 keV, 340 keV and 512 keV are parts of the common system of the fine structure observed in data on nuclear excitations in the files CRF-NRF and are represented as the periods (and stable intervals) equal to integer number n=17-18 of the periods $\delta m_N/(4{\times}17)$=19 keV=$2\delta'$ and $\delta m_N/(8{\times}17)$=9.50 keV=δ' directly observed in data for neutron resonances. Observed in nucleon masses exact rational relation in shifts 8(1.0001(1)) confirmed as systematic effect with analysis of nuclear data was an empirical indication on the presence of very general dynamics connected with charge discreteness and the properties of the symmetry of the fermion system as well as with the nature of the physical condensate in which we live [16]. They were connected with the empirical observation of the distinguished character of the lepton ratio L=13·16-1, with the interconnection between masses of d- and b-quarks ($9m_e$ and $9M_q$) and the coincidence of some ratios between particle masses with the QED radiative correction $\alpha/2\pi$=115.9·10^{-5}. For example, the ratio $m_\mu/M_Z = 115.9 \cdot 10^{-5}$ and ratios m_d/m_b and $m_e/3/\Delta M_\Delta/M_H$ (where ΔM_Δ=147 MeV is the constituent quark mass interaction in NRQCM-model and the M_H is the mass of the scalar field) are close to $\alpha/2\pi$. Color interpretation of the appearance of the value $m_e = 3 \times m_e/3$ as the main SM-parameter in these correlations was considered in [6-15]. Here we describe an additional analysis of data on particle masses which were used for the check of above discussed CODATA relation and its parameter δ=16m_e=2(Δ-m_e).

2. Analysis of data in new binding energy file MDF

We performed the analysis of the updated compilation of the experimental and theoretical data on atomic masses, nuclear binding energies, nucleon separation energies and so-called nucleon residual interactions derived from the differences of nuclear binding energies. The data in MDF are presented in tables containing nuclear binding energies ($E_{\rm B}$), atomic mass excesses of nuclei (ME, $ME = 0$ for ^{12}C by definition), Q-values and separation energies of a single nucleon or several nucleons ($S_{\rm n}$, $S_{\rm p}$, $S_{\rm 2n}$, $S_{\rm 2p}$ etc.). Atomic masses $M_{\rm A}$ are connected with nuclear masses $M_{\rm N}$ by the formula:

$$M_{\rm A}(A,Z) = M_{\rm N}(A,Z) + Z \times m_e - B_{\rm el}(Z) \qquad (2)$$

where $B_{\rm el}(Z)$ is the total binding energy of all removed electrons.

The experimentally found a near constancy of the average binding energy per nucleon suggests the independence of the nuclear density with the atomic weight A and the saturation of the nuclear forces. These two features are represented by the mass formula by Weizsäcker inspired by the liquid-drop model (LDM) by Nils Bohr. The nuclear binding energy as a function of proton and neutron numbers allows the observation of so-called magic numbers corresponding to closed shells, the influence of residual interaction between nucleons and few-nucleon correlations (cluster effects).

An example of residual neutron-proton interaction derived from nucleon separation energies of neighbour nuclei can be seen in Fig.1 (top) for Z=51,53,55. In sum distributions of ε_{n2n} (bottom left) and ε_{n2p} (right) arrows mark values $\varepsilon_o/3$=341 and (2/3)ε_o=682 keV.

Valence nucleon separation energies themselves were found to be close to integers of the parameter 340 keV, while in the sum distribution of all two-proton separation energies $S_{\rm 2p}$ of N-even nuclei ($Z \leq 90$) a periodicity with the parameter ε_o=1022 keV was found.

Such effect is in accordance with maxima at 340 and 680 keV ($\varepsilon_0/3$ and 2$\varepsilon_0/3$) in the sum distributions of the standard parameters of the residual interaction $\varepsilon_{\rm n2n}$=$\Delta S_{\rm n}$(ΔN=2)= =$\Delta E_{\rm B}$ and $\varepsilon_{\rm n2p}$=$\Delta S_{\rm n}$(ΔZ=2)=$\Delta E_{\rm B}$ (see [3]).

The grouping of differences of binding energies can be seen also in the $S_{\rm 2p4n}$ distribution (difference of binding energies of nuclei differing with ^{6}He cluster) in all nuclei with $N \leq$82 (Fig 2, top) and Z=82 (2-nd line right). These sharp maxima are reflections of long-range correlations in nuclear binding energies, clearly connected with the well-known nuclear shells but not reproduced by the existing theoretical models as it can be seen from Table 1 where large difference between observed and theoretical values presented in the last line of the Table 1, for nuclei differing with ΔZ=2, ΔN=4.

The stability of binding energies in light nuclei differing by α-cluster was noticed long ago by F. Everling [17]. Now we see long-range correlation in binding energies [18] of a scale of the effect observed in nucleon masses (CODATA relation), including long-range correlations in case of 4α cluster (the last column in Table 1, near-magic ^{39}K).

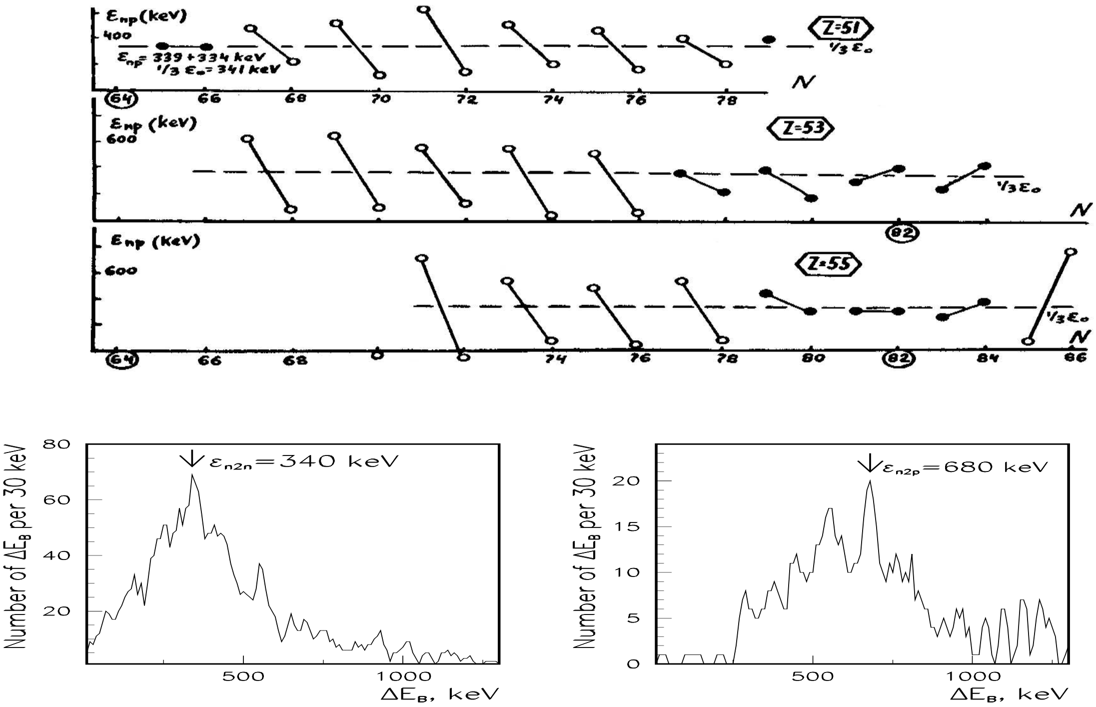

Fig. 1. *Top:* Parameters of the residual interaction ε_{np} from differences of S_p in Z-odd nuclei differing with ΔN=1. Mean value 341 keV=$\varepsilon_o/3$ is given by the horizontal line.
Bottom: Distributions of the residual nucleon interaction parameters ε_{n2n} and ε_{n2p}.

Table 1. Closeness of $\Delta E_{\rm B}$ (keV) to $45\varepsilon_0$=46.0 MeV (*center*) for nuclei differing by $2\Delta Z=\Delta N$=4, and to $90\varepsilon_0$=92.0 MeV (at *right*) for nuclei with $2\Delta Z=\Delta N$=8. Estimations with the FRDM model (*bottom lines*) do not show such effect.
For light nuclei differing by $\Delta Z=\Delta N$=8 (4α-cluster) $\Delta E_{\rm B}$ is close to $18\times 8\varepsilon_0$; the difference in the near-magic ^{39}K with $18\times 8\varepsilon_0$ is within 10 keV [3].

Nucleus	^{135}Cs	^{137}Cs	^{135}La	^{137}La	^{139}La	^{136}Ce	^{138}Ce	^{140}Ce	^{139}La	^{39}K
Z	55	55	57	57	57	58	58	58	57	19
N	80	82	78	80	82	78	80	82	82	20
$\Delta E_{\rm B}$	45946	45970	46018	45927	46024	46087	45997	45996	91975	147160
$n\varepsilon_0$	45990	45990	45990	45990	45990	45990	45990	45990	91980	147168
diff.	-44	-20	28	-63	34	97	7	6	-5	8
Theory	46620	46340	45950	46820	46970	45960	46850	47160	93200	147450
diff.	630	350	-40	830	980	-30	860	1170	1220	282

Tuning effect in light nuclei differing with four and two α-clusters is seen as maxima at exactly rational (2:1) values 147.3 and 73.6 MeV (Fig.2, 2-nd line left and center right). Appearance of maximum at 441 MeV in spacing distribution in binding energies of all odd-odd nuclei (Fig.2, left) should be checked additionally. Application of the special Adjacent Interval Method (AIM-method described later) to all intervals in light nuclei which belong to maximum at 73.6 MeV=16Δ resulted in the clear system of intervals with the period $2\Delta=9\varepsilon_o=18m_e$ [18]. Performed analysis of nuclear data is the indirect confirmation of the reality of CODATA relation between masses of nucleons and the electron mass. Direct confirmations were obtained during the preliminary analysis of particle mass spectrum.

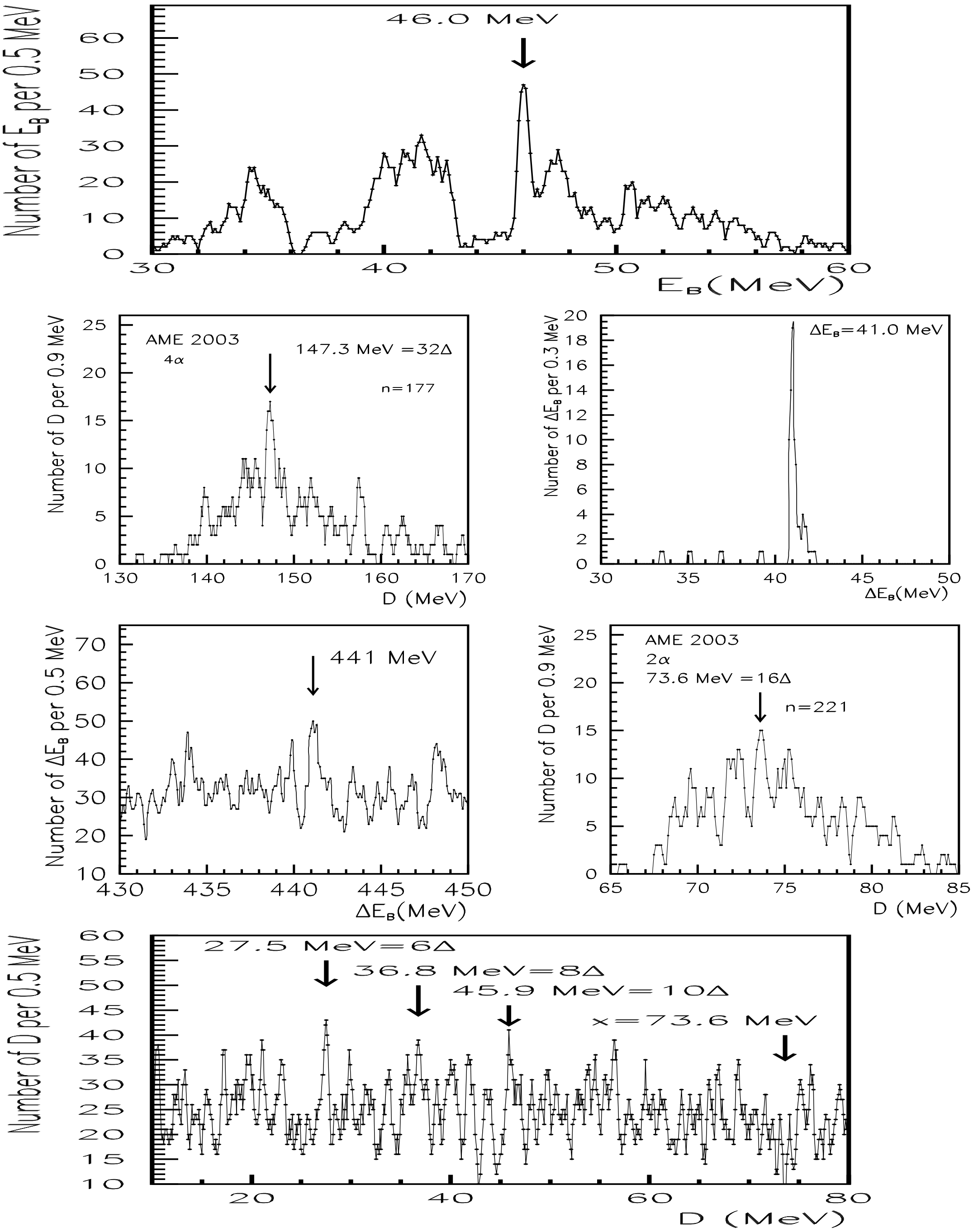

Fig. 2. *Top:* Grouping of differences of binding energies ΔE_B at 46.0 MeV=10Δ.
2-nd line, left: Grouping of ΔE_B at 147.3 MeV=32Δ in light nuclei differing with 4α-clusters.
2-nd line, right: The same at 41.0 MeV=32Δ=40ε_o for Z=82 nuclei differing with the ^{6}He-cluster.
Center left: Grouping of ΔE_B at 441 MeV=4$\times$147.3 MeV=4$\cdot$32Δ in all odd-odd nuclei.
Center right: Grouping of ΔE_B at 73.6 MeV=16Δ=16$\cdot$98ε_o in all light nuclei (Z$\leq$26).
Bottom: Grouping of adjacent intervals ΔE_B for selected x=ΔE_B=73.6 MeV=16Δ in total ΔE_B distribution in light nuclei, Δ=9m_e=4.6 MeV.

3. Data on particle masses in PDG compilation

In Table 2 all particle masses from the recent PDG-2016 compilation [4] are presented in the order as they appear in Summary PDG-Tables. Values with uncertainties larger than 0.6 MeV are marked with one asterisk, values without rounding up and with uncertainties less than 6 MeV are marked with two asterisks. Corresponding numbers of mass values are 169 (total number of mass values), 69 (accurately known), 44 and 27 values (less certain, with one or two asterisks, respectively).

Table 2. Particle masses [4] (in MeV) known with the uncertainty less than 6 MeV.

	Particle		m_i	uncert.		Particle		m_i	uncert.
1	leptons					$K^{\circ***}$	$1/2(0^-)$	497.611	
	electron, ν		0.0			$K^*(892)^{*\pm}$	$1/2(1^-)$	891.66	0.26
	$\boxed{\mu}$		105.658			$K^*(892)^{*\circ***}$	$1/2(1q-)$	895.81	0.19
	τ		1776.82	0.16		$K_1(1270)^{**}$	$1/2(1^+)$	1272	7
2	Unflavored mesons					$K_1(1400)^{**}$	$1/2(1^+)$	1403	7
	f_π		130.7	0.4		$K_2^*(1430)^{\pm*}$	$1/2(2^+)$	1425.6	1.5
	$\pi^{\circ***}$	$1^-(0^-)$	134.977			$K_2^*(1430)^{\circ*}$	$1/2(2^+)^{***}$	1432.4	1.3
	$\pi^\pm$	$1^-(0^-)$	139.570			$K_2(1770^{**}$	$1/2(2^-)$	1473	8
	η	$0^+(0^{-+})$	547.862	0.016		$K_3^*(1780)^{**}$	$1/2(3^-)$	1776	7
	$\rho(770)$	$1^+(1^{--})$	775.26	0.25		$K_4^*(2045)^{**}$	$1/2(4^+)$	2045	9
	$\omega(782)$	$0^-(1^{--})$	782.65	0.12	4	charmed	mesons		
	$\eta'(958)$	$0^+(0^{-+})$	957.78	0.06		D°	$1/2(0^-)$	1864.83	0.05
	$\phi(1020)$	$0^-(1^{--})$	1019.461	0.019		$D^\pm$	$1/2(0^-)$	1869.58	0.09
	$b_1(1235)^*$	$1^+(1^{+-})$	1229.5	3.2		$D^*(2007)^\circ$	$1/2(1^-)$	2006.85	0.05
	$f_2(1270)^*$	$0^+(2^{++})$	1275.5	0.8		$D^*(2010)^\pm$	$1/2(1^-)$	2010.28	0.05
	$f_1(1285)$	$0^+(1^{++}$	1282.0	0.5		$D_1(2420)^\circ$	$1/2(1^+)$	2420.8	0.5
	$\eta(1295)^{**}$	$0^+(0^{-+}$	1294	4		$D_2^*(2460)^{\circ***}$	$1/2(2^+)$	2460.57	0.15
	$a_2(1320)$	$1^-(2^{++}$	1318.3	0.5		$D_2^*(2460)^{\pm*}$	$1/2(2^+)$	2465.4	1.3
	$\eta(1405)^*$	$0^+(0^{--})$	1408.8	1.8	5	charmed, strange	mesons		
	$f_1(1420)^*$	$0^+(1^{++})$	1426.4	0.9		$D_s^\pm$	$0^+(0^-)$	1968.27	0.10
	$\eta(1475)^{**}$	$0^+(0^{-+}$	1476	4		$D_s^{*\pm}$	$0(?^?)$	2112.1	0.4
	$f_0(1500)^{**}$	$0^+(0^{++})$	1504	6		$D_{s\circ}^*(2317)^\pm$	$0(0^+)$	2317.7	0.6
	$f_2'(1525)^{**}$	$0^+(2^{++})$	1525	5		$D_{s1}(2460)^\pm$	$0(1^+)$	2459.5	0.6
	$\pi_1(1600)^{**}$	$1^-(1^{-+})$	1662	8		$D_{s1}(2536)^\pm$	$0(1^+)$	2535.10	0.06
	$\eta_2(1645)^{**}$	$0^+(0^{-+})$	1617	5		$D_{s2}^*(2573)^*$	$0(2^+)$	2569.1	0.8
	$\omega_3(1670)^{**}$	$0^-(3^{--})$	1667	4		$D_{s1}^*(2700)^{\pm*}$	$0(1^-)$	2708.3	3.4
	$\pi_2(1670)^*$	$1^-(2^{-+})$	1672.2	3.0	6	bottom	mesons		
	$\rho_3(1690)$	$1^+(3^{--})$	1688.80	2.1		$B^\pm$	$1/2(0^-)$	5279.31	0.15
	$f_0(1710)^{**}$	$0^+(0^{++})$	1723	6		$B^{\circ***}$	$1/2(0^-)$	5279.62	0.15
	$\phi_3(1850)^{**}$	$0^-(3^{--})$	1854	7		B^*	$1/2(1^-)$	5324.65	0.25
	$a_4(2040)^{**}$	$1^-(4^{++}$	1995	8		$B_1(5721)^{+*}$	$1/2(1^+)$	5725.9	2.7
3	strange	mesons				$B_1(5721)^{\circ*}$	$1/2(1^+)^{***}$	5726.0	1.3
	$K^\pm$	$1/2(0^-)$	493.677			$B_2^*(5747)^{-1*}$	$1/2(2^+)$	5737.2	0.7

Table 2. Continued.

	Particle		$\mathrm{m_i}$	uncert.		Particle		$\mathrm{m_i}$	uncert.
	$B_2^*(5747)^\circ$	$1/2(2^+)$***	5739.5	0.7		$\chi_{b0}(2P)$	$0^+(0{+}{+})$	10232.5	0.4
	$B_J(5970)^+$**	$1/1(?^?)$	5964	5		$\chi_{b1}(2P)$	$0^+(1{+}{+})$	10255.46	0.50
	$B_J(5970)^\circ$**	$1/1(?^?)$***	5971	5		$\chi_{b2}(2P)$	$0^-(2{+}{-})$	10268.65	0.50
7	bottom strange	mesons				$\Upsilon(3S)$	$0^-(1{-}{-})$	10355.2	0.5
	B_s°	$0(0^-)$	5366.82	0.22		$\chi_{b1}(3P)$*	$0^+(1{+}{+})$	10512.1	2.3
	B_s^{**}	$0(1^-)$	5415.4	1.5		$\Upsilon(4S)$*	$0^-(1{-}{-})$	10529.4	1.2
	$Bs1(5830)^\circ$	$0(1^+)$	5828.63	0.27	1	$X(10610)^{\pm}$*	$1^+(1^+)$	10607.2	2.0
	$B_{s2}^*(5640)^\circ$	$0(2^+)$	5839.84	0.18		$X(10610)^\circ$**	$1^+(1^+)$	10609	6
8	bottom charmed					$\Upsilon(10860)$**	$0^-(1{-}{-})$***	10891	6
	B_c^{**}	$0(0^-)$	6275.1	1.0	1		baryons		
9	$c\bar{c}$“	mesons				p	$1/2(1/2^+)$***	938.2721	
	$\eta_c(1S)$	$0^+(0^{-+})$	2983.4	0.5		n	$1/2(1/2^+)$	939.5654	
	$J/\psi(1S)$	$0^-(1^{--})$	3096.90	0.01		Λ	$0(1/2^+)$	1115.683	
	$\chi_{c0}(1P)$	$0^+(0^{++})$	3414.75	0.31		$\Lambda(1405)1/2^-$*	$0(1/2^-)$	1405.1	1.3
	$\chi_{c1}(1P)$	$0^+(1^{++})$	3510.66	0.07		$\Lambda(1520)3/2^-$*	$0(3/2^-)$	1519.5	1.0
	$h_c(1P)$	$?^?(0^{+-})$	3525.38	0.11		Σ^+	$1(1/2^+)$***	1189.37	0.07
	$\chi_{c2}(1P)$	$0^+(2^{++})$	3556.20	0.09		Σ°	$1(1/2^+)$	1192.642	
	$\eta_c(2S)$*	$0^+(0^{-+})$	3639.2	1.2		Σ^-	$1(1/2^+)$***	1197.45	0.03
	$\psi(2S)$	$0^-(1^{--})$	3686.10	0.03		$\Sigma(1385)^+$	$1(3/2^+)$***	1382.80	0.35
	$\psi(3770)$	$0^-(1^{--})$	3773.13	0.35		$\Sigma(1385)^\circ$*	$1(3/2^+)$	1383.7	1.0
	$\psi(3823)$*	$?^?(2^{--})$	3822.2	1.2		$\Sigma(1385)^-$	$1(3/2^+)$***	1387.2	0.5
	$X(3872)$	$0^+(1^{++})$	3871.69	0.17		Ξ°	$1/2(1/2^+)$	1314.86	0.20
	$X(3900)$*	$1^+(1^{+-})$	3886.6	2.4		Ξ^-	$1/2(1/2^+)$	1321.71	0.07
	$X(3915)$*	$0^+(?^{++})$	3918.4	1.9		$\Xi(1530)3/2^{+\circ}$	$1/2(3/2^+)$	1531.80	0.32
	$\chi_{c2}(1P)$*	$0^+(2^{++})$	3927.2	2.6		$\Xi(1530)3/2^-$***	$1/2(3/2^+)$	1535.0	0.6
	$X(4020)$*	$1(?^?)$	4024.1	1.9		$\Xi(1820)3/2^-$**	$1/2(3/2^-)$	1823	5
	$\psi(4040)$**	$0^-(1{-}{-})$	4039	1	1	$\Xi(2030)$**	$1/2(\geq 3/2^?)$	2025	5
	$X(4140)$*	$0^+(??{+})$	4146.9	3.1		Ω^-	$0(3/2^+)$	1673.45	0.29
	$\psi(4160)$**	$0^-(1{-}{-})$	4191	5		$\Omega(2250)^-$**	$0(?^?)$	2252	9
	$X(4260)$**	$?^?(1{-}{-})$	4251	9	2	charmed	baryons		
	$X(4360)$**	$?^?(1{-}{-})$	4346.9	6		Λ_c^+	$0(1/2^+$	2286.46	0.14
	$\psi(4415)$**	$0^-(1{-}{-})$	4421	4		$\Lambda_c(2595)^+$	$0(1/2^-)$	2592.25	0.28
	$X(4660)$**	$?^?(1{-}{-})$	4643	9		$\Lambda_c(2625)^+$	$0(3/2^-)$	2628.11	0.19
10	$b\bar{b}$	mesons				$\Lambda_c(2880^+)$	$0(5/2^+)$	2881.53	0.35
	$\eta_b(1S)$*	$0^+(0{-}{+})$	9399.0	2.3		$\Lambda_c(2940^+)$*	$0(5/2^+)$	2939.3	1.5
	$\Upsilon(1S)$	$0^-(1{-}{-})$	9460.30	0.26		$\Sigma_c(2455)^{++}$	$1(1/2^+)$***	2453.97	0.16
	$\chi_{b0}(1P)$	$0^+(0{+}{+})$	9859.44	0.42		$\Sigma_c(2455)^+$	$1(1/2^+)$***	2452.9	0.4
	$\chi_{b1}(1P)$	$0^+(0{+}{+})$	9892.78	0.26		$\Sigma_c(2455)^\circ$	$1(1/2^+)$	2453.75	0.14
	$h_b(1P)$*	$?^?(1{+}{-})$	9899.3	0.8		$\Sigma_c(2520)^{+-}$	$1(3/2^+)$***	2518.41	0.21
	$\chi_{b2}(1P)$	$0^+(2{+}{+})$	9912.21	0.26		$\Sigma_c(2520)^+$*	$1(3/2^+)$***	2517.5	2.3
	$\Upsilon(2S)$	$0^-(1{-}{-})$	10023.26	0.31		$\Sigma_c(2520)^\circ$	$1(3/2^+)$	2518.48	0.20
	$\Upsilon(1D)$*	$0^-(2{-}{-})$	10163.7	1.4		$\Sigma_c(2800)^{+-}$**	$1(3/2^+)$***	2801	6

Table 2. Continued.

	Particle		m_i	uncert.		Particle		m_i	uncert.
	$\Sigma_c(2800)^{\circ **}$	$1(3/2^+)$	2906	7	13	bottom	baryons		
	Ξ_c^+	$1/2(1/2^+)$	2467.93	0.40		Λ_b°	$0(1/2^+)$	5619.51	0.23
	Ξ_c°	$1/2(1/2^+)$	2470.85	0.40		$\Lambda_b(5912)^\circ$	$0(1/2^-)$	5912.11	0.26
	$\Xi_c'^{+*}$	$1/2(1/2^+)^{***}$	2575.7	3.0		$\Lambda_b(5920)^\circ$	$0(3/2^-)$	5919.81	0.23
	$\Xi_c'^{\circ *}$	$1/2(1/2^+)$	2577.9	2.9		Σ_b^{+*}	$1(1/2^+)$	5811.3	1.9
	$\Xi_c(2645)^+$	$1/2(3/2^+)^{***}$	2645.9	0.5		Σ_b^-	$1(1/2^+)^{***}$	5815.5	18
	$\Xi_c(2645)^\circ$	$1/2(3/2^+)$	2645.9	0.5		Σ_b^{*+*}	$1(3/2^+)$	5832.1	1.9
	$\Xi_c(2790)^{+*}$	$1/2(1/2^-)^{***}$	2789.1	3.2		Σ_b^{*-*}	$1(3/2^+)^{***}$	5835.1	1.9
	$\Xi_c(2790)^{\circ *}$	$1/2(1/2^-)$	2791.9	3.3		Ξ_b^{-*}	$1/2(1/2^+)$	5794.5	1.4
	$\Xi_c(2815)^{+*}$	$1/2(3/2^-)^{***}$	2816.6	0.9		Ξ_b°	$1/2(1/2^+)$	5791.9	0.5
	$\Xi_c(2815)^{\circ *}$	$1/2(3/2^-)$	2819.6	1.2		$\Xi'/_b(5935)^-$	$1/2(1/2^+)$	5935.02	0.05
	$\Xi_c(2970)^{+*}$	$1/2(?^?)^{***}$	2970.7	2.2		$\Xi/_b(5945)^{\circ *}$	$1/2(3/2^+)$	5948.9	1.6
	$\Xi_c(2970)^{\circ *}$	$1/2(?^?)$	2968.0	2.6		$\Xi/_b^*(5955)^-$	$1/2(1/2^+)$	5955.33	0.13
	$\Xi_c(3055)^*$	$1/2(?^?)$	3055.1	1.7		Ω_b^{-*}	$0(3/2^+)$	6046.4	1.9
	$\Xi_c(3080)^+$	$1/2(?^?)^{***}$	3076.94	0.28	14	exotic	baryons		
	$\Xi_c(3080)^{\circ *}$	$1/2(?^?)$	3079.9	1.4		$P_c(4450)^{+*}$		4449.8	3.0
	$\Omega_c^{\circ *}$	$0(1/2^+)$	2695.2	1.7					
	$\Omega_c(2770)^{\circ *}$	$0(3/2^+)$	2765.9	2.0					

To avoid the grouping effect in mass values due to small differences between masses of members of multiplets (n-p mass difference 1.3 MeV, $\pi^{\pm}$-π°=4.6 MeV etc.) 29 values (out of n=168) were excluded from the analysis (charged baryon and neutral meson masses, namely, proton mass, π° mass etc.). Distribution of differences between all remaining 139 values (for three differing averaging intervals Δ=3, 5 and 9 MeV in the ideohistograms) are presented in three parts of Fig.3-4 (separately for the regions of mass differences 0-1500 and 1500-4500 MeV).

Maxima in obtained distributions of mass differences could be considered in line of earlier introduced in the literature theoretical or empirical observations. We start with mentioning the stable character of the interval close to the mass of the charged pion (ΔM=140 MeV, Fig.3). According to Mac-Gregor [19] a probability of an accidental grouping of these intervals (and rational to them) is very low. The groping of ΔM values in the vicinity of 104 MeV (maximum for ΔM=9 MeV, Fig.3 bottom) takes place at the values close to the muon mass m_μ=106 MeV and the estimated value of the strange quark mass m_s=98 MeV [4]. In case of vector meson masses it was noticed by R. Sternheimer [20] that the difference between masses of K^* and ω meson 892 MeV-783 MeV=109 MeV is close to the muon mass (due to the strangeness). The above discussed tuning effect in particle masses and the discreteness with the period $\delta=16m_e$=8.176 MeV (n=13 and n=17 for muon and pion masses) is confirmed with the fact that both maxima at low energies (ΔM=16 MeV and 48 MeV=3·16 MeV in the distribution with Δ=5 MeV, Fig.3 center) are corresponding to numbers n=2 and n=6 of the period $\delta=16m_e$.

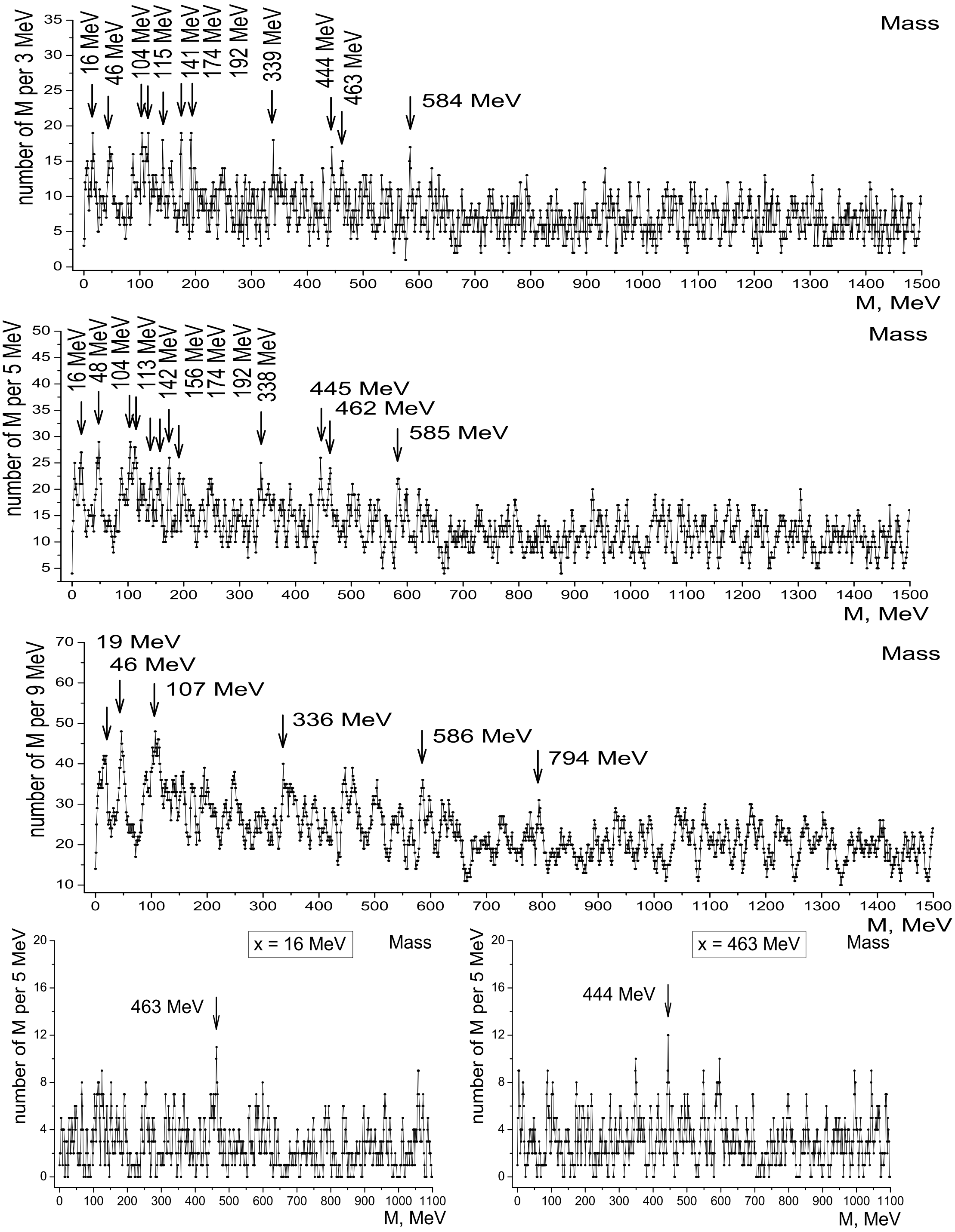

Fig. 3. *Top:* Distribution of differences between particle masses ΔM in the region 0-1500 MeV and averaging interval of the histogram 3 MeV. Stable intervals (discussed in the text) are marked with arrows.
Center: The same for averaging intervals 5 MeV and 9 MeV. Intervals 16 MeV, 48 MeV, 107 MeV$\approx m_\mu$ and 141 MeV$=m_\pi^\pm$ are close to integer numbers of the parameter $\delta = 16 m_e$ found in CODATA relations with the masses of nucleons. *Bottom:* Application of the AIM Method to show a systematic character of the appearance in the particle mass spectrum of close to each other and adjacent intervals 444-463 MeV (differing with about 16 MeV=2δ). Maximum at 463 MeV in the left distribution (AIM intervals in upward direction from x=16 MeV) is in agreement with the maximum at 444 MeV in the right distribution (AIM for fixed x=463 MeV).

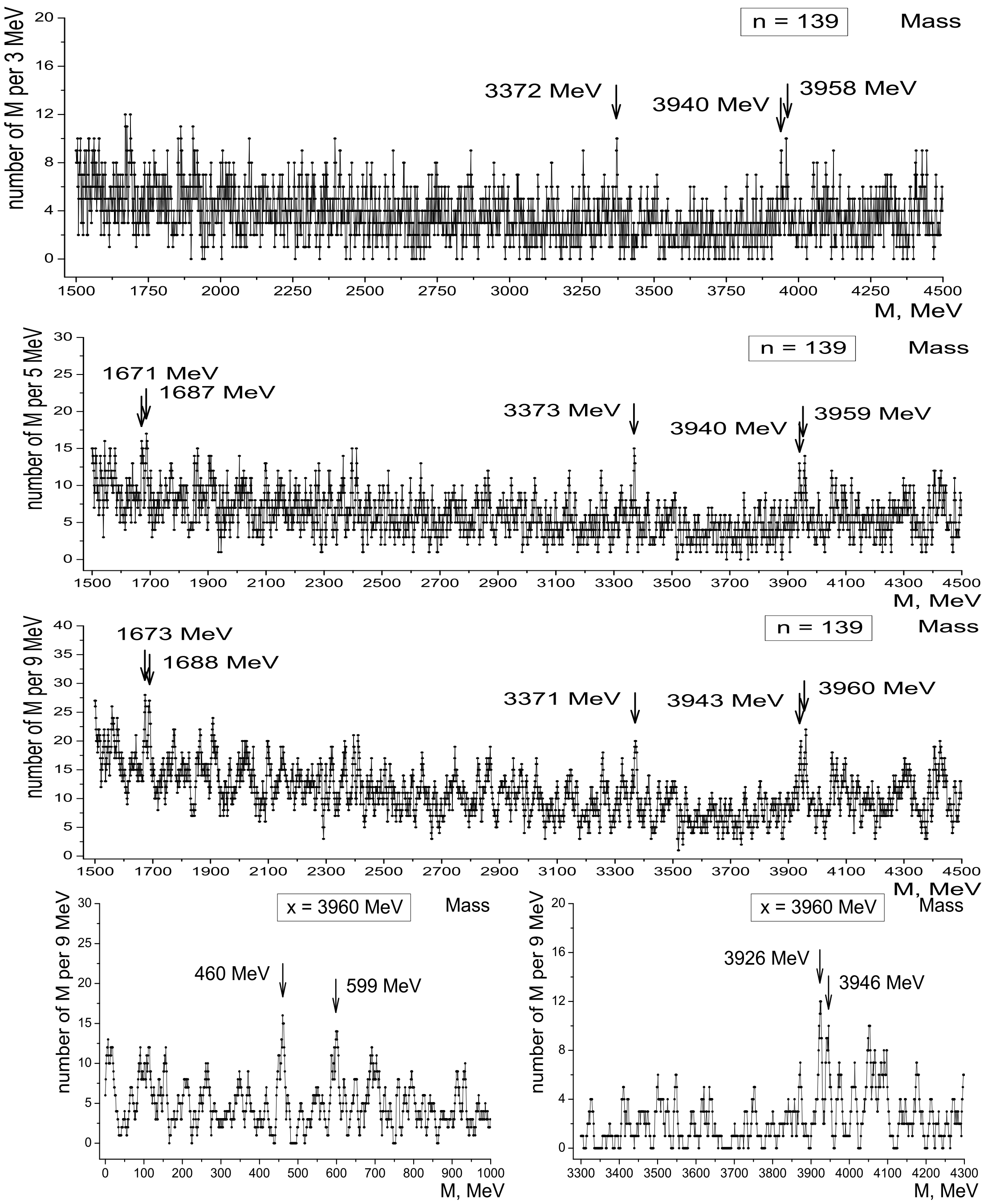

Fig. 4. *Top:* Distribution of differences between particle masses ΔM in the region 1500 -4500 MeV and averaging interval of the histogram 3 MeV. Stable intervals (discussed in the text) are marked with arrows.
Center: The same for averaging intervals 5 MeV and 9 MeV. Intervals 3943 MeV, 3960 MeV are close to bottom quark mass estimation 4.2 GeV [4]. *Bottom:* Application of the Adjacent Interval Method (AIM) to show a systematic character of the appearance in the particle mass spectrum of close to each other and adjacent intervals 3926 MeV, 3946 MeV and 3960 MeV as well as the interval 460 MeV (previous figure). Maxima at 460 MeV in the left distribution and 3926 MeV and 3946 MeV in the right distribution (both are AIM intervals in upwards direction for fixed x=3960 MeV) correspond to relations between mass intervals close to m_b and $m_b/9 = M_q$=441 MeV known as initial baryon quark mass in NRCQM Model [6-15].

Maximum of stable intervals ΔM=174 MeV in Fig.3 includes differences between masses of the Λ-hyperon and the neutron (1115.7-939.6 MeV=176.1 MeV). These two values (shown as Λ and N in the main Figure in the previous work [6-15]) and correspond to n=8·17=136 and n=115 in the tuning effect considered therein. The value 174 MeV is larger than 21δ=171.7 MeV due to the fact that Λ-hyperon mass is very close to $8m_\pi^\pm$=8·139.57 MeV=1116.6 MeV which is somewhat larger than 8·17δ=1111.9 MeV. Charged pion mass is close to $17\delta+m_e$ (see main Table in these works) and hence m_Λ deviates from 136δ with about $8m_e$=4 MeV.

Two doublets of maxima in ΔM-distribution at 444-463 MeV (Fig.3 top, ΔM=3 MeV) and 3943-3960 MeV (Fig.4 bottom, ΔM=9 MeV) could be connected with the manifestation of the two well-known dynamics, namely:
1) with the constituent quark mass origin in NRCQM-model (M_q=441 MeV=$m_\Xi/3$ [21,22]) due to the gluon quark dressing effect based on QCD [23], and
2) the spectroscopy of the bottom quark – one of the heaviest fundamental component of the Standard Model with the estimated value m_b=4180(40) MeV [4]. We show later that mass parameters of both effects are interconnected.

Observed maximum at 445 MeV (Fig.3, center) includes two pairs of intervals between masses of K°, the neutron, Σ° and ω°, b_1-meson and Ω^-. The stable character of such intervals was noticed by R. Sternheimer and P. Kopotkin [20,24], and now it is explained as the QCD effect in the Nonrelativistic Constituent Quark Model [21-23]. A special correlation method of data analysis (AIM Adjacent Interval Method) was used to find out intervals in the spectra (of the energies or the masses) which are situated close to each other (or adjacent). Fixating in the mass spectrum all small intervals x=ΔM=16(2) MeV we plot sum spacing distribution of all intervals Δ^{AIM} from the bottom masses (of the interval x) up to all larger masses (upwards direction in AIM method). Appearance of eleven intervals Δ^{AIM}=463(2) MeV (Fig,3 bottom left) can be checked with the presence of the maximum at 444 MeV in the downwards distribution for x=463 MeV (Fig.3 bottom right). It means that both intervals 444-463 MeV are systematically appear together (adjacent) in the different parts of the particle mass spectrum. These intervals are close to the parameter in NRQCM 441 MeV=3·18δ=$m_\Xi^-/3$ [21,22,24]. Further theoretical and empirical analysis is needed for explaining observed tuning effect.

Stable interval Δ^{AIM}=460 MeV (close to M_q=441 MeV) appears also in the adjacent interval AIM-distribution (the AIM upward direction) for the fixed large stable intervals x=3960 MeV seen as the strongest maxima in all parts of Fig.4 right (namely, ΔM=3957(1) MeV, 3959(2) MeV and 3960(4) MeV, for averaging intervals 3-5-9 MeV). These intervals are seen as a part of systems of maxima separated with small intervals close to 16 MeV=2δ. Such a system consisting of Δ^{AIM}=3926 MeV and 3946 MeV in Δ^{AIM}-distribution (adjacent upwards distribution) for x=3960 MeV is shown in Fig.4 bottom right. Mentioned maximum in this system with the energy 3957(1) MeV (on the top distribution in Fig.4 right) contains two exactly coinciding intervals:
1) the value ΔM=3957.4 MeV between the $b\bar{b}$ meson with M=10232.5(4) MeV ($\chi_{b0}(2P)$, $0^+(0^{++})$) and the bottom charmed meson with M=6275.1(10) MeV (B_c^*, $0(0^-)$), and
2) practically the same value ΔM=3957.4 MeV between the latter value M and the charmed strange meson ($D_{s\circ}^*(2317)^\pm$, $0(0^+)$) mass M=2317.7(6) MeV [4] (Table 2).

Observed exact coincidence of two independent interval clearly connected with the presence of two and one bottom quarks in the structure of the relevant mesons could be compared with the observed exact relation in CODATA data (exact multiplicity with the period $16m_e = \delta$=8.176 MeV). The ratio n=484.026 between the large interval under consideration (3957.4 MeV) and the universal parameter δ of the tuning effect, is close to n=484=486-2 as well as n=486-4 and 486-6 for masses of other two members of the above discussed system of meson masses, situated within the mass region of the bottom quark mass m_b=4.18 GeV [4]. It allows to notice that n=486=9·54 corresponds to the mass 3974 MeV=9M_q with M_q=441 MeV, introduced empirically long ago by R. Sternheimer and P. Kropotkin [20,24]. The ratio between the vector boson mass (M_Z) and the discussed stable interval is M_Z/M_q=91187(2) MeV/3957.4 MeV=23.042. It corresponds to the proximity of the ratio between M_z and M_q to the lepton ratio L=207=16·13-1=9·23 (a reflection of the empirically found coincidence of ratios m_μ/M_Z and m_e/M_q with the QED radiative correction $\alpha/2\pi$ [6-15]).

Combined analysis of all existed data on particle masses and nuclear data (including neutron resonance data) provide an effective way for further development of the Standard Model.

4. Conclusions

Comparison of results obtained from the analysis of valence nucleon interaction with the CODATA relation between masses of nucleons and the electron allowed the conclusion [6-15] on existence of the discreteness in parameters of the Standard Model - masses of leptons and fundamental fields as well as some principal hadrons (pions, vector mesons and quarks). We expanded here such combined method of data analysis on the total spectrum of particle masses from PDG compilation [4].

Neutron physics is a part of the nuclear physics based on the QCD and the Standard Model (SM) - the theory of all interaction except the gravitation and the origin of dark matter. Three SM-components, namely, QCD, weak interaction and QED are interconnected between themselves. It is evident from the empirically observed tuning effect in particles masses and nuclear data consisted of the presence of additional relations between masses of hadrons (connected with the QCD-based gluon quark dressing effect) and such well known QED/SM parameters as the lepton masses and radiative corrections of the type $\alpha/2\pi = 115.9 \cdot 10^{-5}$. A ratio between masses of well-known particles which are commonly considered as parameters of the Standard Model - the muon mass and the mass of the vector field $m_\mu/M_Z = 115.9 \cdot 10^{-5}$ turns to be very close to this QED correction.

Empirically observed in neutron resonance spacing/position superfine-structure intervals 5.5 eV-11 eV-88 eV (noticed by W.Havens, K.Ideno and others) and fine-structure intervals 9.5 keV-21 keV-492 keV (noticed by M.Ohkubo and others) were interconnected later with two systems of fine-structure intervals with periods 9.5 keV×(n=17,18), namely, 161 keV and 170 keV, rationally connected with charge splittings of the nucleon $\delta m_N/8$=161 keV and the electron $m_e/3$=170 keV. Above mentioned exact relations between nucleon masses, δm_N and m_e (so-called CODATA relations) were confirmed recently with the discreteness (with the same parameters) in excitations of nuclei ^{37,38,43}S,^{41}K,^{41}Ca,^{53,55}Mn,^{53,59}Co.^{53,59,63}Ni and ^{59,71,73}Cu with different configurations of valence nucleons (Tables 3,4 in [13,14]). Neutron resonance data collected in PNPI (as the file NRF-5 for all nuclei) could be used for analysis of superfine and fine structure effects. For example. stable fine structure intervals 66 eV and 85 keV equal to D=9.5 keV×(7 and 9) were found earlier in the resonance data for Cr and Fe isotopes. In neutron data for

Br- and Sb-isotopes an indirect confirmation of the presence of such small factor (close to QED correction) was noticed as nonstatistical effects in spectrum (the splitting 1.1 keV$\approx \varepsilon'$ of the state at 1022 keV=$\varepsilon_\circ$) and in spacing distributions of ^{80}Br (D=749 eV) as well as in ^{124}Sb. Neutron resonance data for both these isotopes were obtained long ago and should be remeasured with the better resolution.

The direct manifestation of parameters of the tuning effect in nuclear binding energies (similar to that shown in Fig.2 and Table 1 using data from AME-2003 and MDF compilations) was produced from data in AME-2016. These data with the combination with values of the spin and spectroscopic factors from CRF is planned to be used for a study of the origin of the observed here discreteness (tuning effect) with periods m_e and $9m_e = \Delta$ (Fig.2 bottom). Independent confirmation of nuclear tuning effect has a fundamental meaning for SM-development. Possibilities of modern PC should be used in production of multidimensional correlation program.

The application of the above mentioned multidimensional correlation programs to data on particle masses could provide a further SM-development in line with the Y. Nambu suggestions [6-15,25].

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