DEVELOPMENT OF THE GLOBAL CONSTITUENT QUARK MODEL

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Introduction

Collecting of manifestation of well-known QED parameters – the electron mass m_e = 511 keV and radiative correction $\alpha/2\pi$ was started in 1955 after the First Geneve conference, at which the coincidence of neutron resonances Pu and Am was reported. Systematic character of nuclear nonstatistical effects was cosidered in a talk at the Albany conference in 1971. In Fig. 1 from this talk stable intervals in particle masses are expressed in units of $16m_e=\delta$.

This parameter was introduced by the author from proximity of the doubled value of pion β-decay energy to $16m_e$, and proximity of masses of the muon and pion to $13×16m_e - m_e$ and $17×16m_e + m_e$.

Y. Nambu noticed empirical relations between masses of pions and baryons $m_N = m_\mu + 6m_\pi$, $m_\Lambda = 8m_\pi$. This means that nucleon mass is close to $115\delta = 115 ×16m_e$, $115=13+6×17$.

P. Kropotkin introduced the value $M_q=m_\Xi/3=441$ MeV$=m_e(\alpha/2\pi)^{-1}$ used later as parameter in the NCQM model.

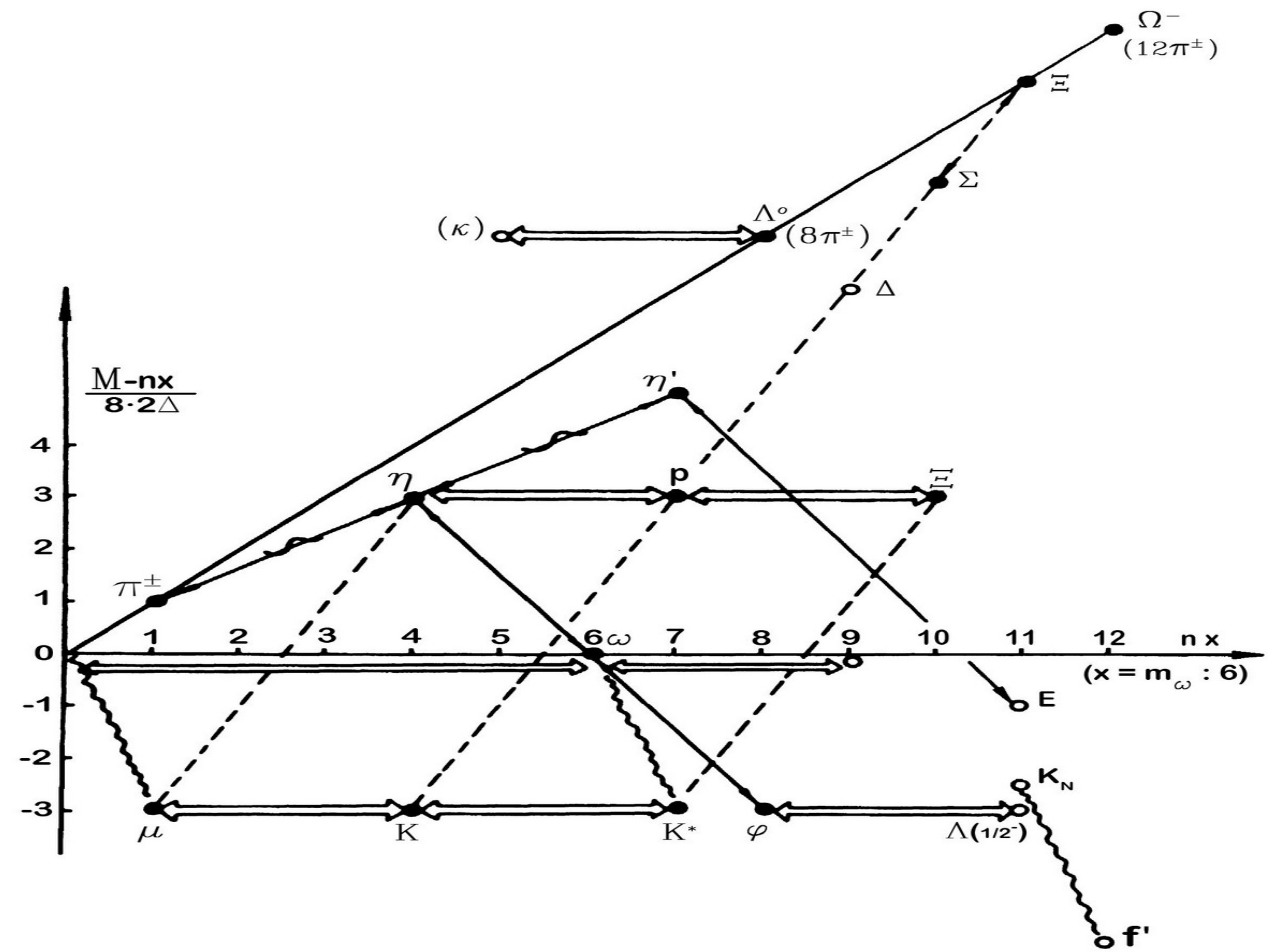


Fig. 1. Relations in particle masses found by G. Wick (horizontal arrows) and R. Sternheimer (dotted lines). Period 130.7 MeV=f_π=16·2·8m_e≈m_ω/6 is subtracted from mass values, the residuals are expressed in units 16m_e=δ.

The electron mass, QED radiative correction $\alpha/2\pi$ and their product $M_q = me(\alpha/2\pi)^{-1}$ are parameters of Electron-based Constituent Quark Model (ECQM), which contains integer representation of particle masses with a period of $16m_e=\delta$. The muon mass $13\delta - m_e$, pion parameters $f_\pi = 130$ MeV$=16\delta$, $m_\pi=140$ MeV$=17\delta+ m_e$ and $\Delta M_\Delta = 147$ MeV$= 18\delta$, and parameters of the NRCQM (Nonrelativistic Constituent Quark Model) $M_q=3\Delta M_\Delta = 441$ MeV, $M^\omega_q=3f_\pi=391$ MeV correspond to the unique common discreteness parameter - the period $\mathbf{16m_e = \delta}$ (with N=13, 16, 17, 18, 54=3×18, 3×16=48).

Nucleons are the main objects of nuclear physics, which, as part of QCD (Quantum Chromodynamics), a component of the Standard Model (SM) - a theory of all interactions, except gravitations. The electron is the main object of quantum electrodynamics (QED), another SM component. We describe here and in the QCD-21 conference report an empirical symmetry motivated and electron-based approach to the development of the Standard Model.

Relations between masses of nucleons and the electron (named the CODATA relations) are determined now very accurately. A ratio of neutron and electron masses $m_n/m_e = 1838.6836605(11)$ means that the shift $\delta m_n=161.6491(6)$ keV from integer values m_e $n=115\times16-1$ is exactly 1/8 of the nucleon mass splitting $\delta m_N=1293.3322(4)$ keV, or $\delta m_N:\delta m_n=8.00086(3)\approx 8\times1.000(1)$. This very unexpected result means an existence of an exact relations between masses of nucleons and electron

$$m_n = 115\cdot16m_e - m_e - \delta m_N/8$$

$$m_p = 115\cdot16m_e - m_e - 9\delta m_N/8.$$

Y. Nambu noted that “ a) When we discover new phenomena which we do not understand, the first thing to do is to collect data and try to find some empirical regularities among them, b) one next tries to build concrete models, c) finally there emerges a real theory… Standard Model qualifies as such a theory “. We discuss here the development of the Electron-based Constituent Quark Model and some aspects of modern Standard Model.

He continued: „ Standard Model … is theoretically unsatisfactory ...
a) the unification of forces is only partially realized, and b) there are too many input parameters, especially concerning the masses, which are not explained. The nature can be at the same time more complicated than we think, and simpler in a way we do not know yet. … we are now at the step of a new cycle. The mass problem is already an early signal for it.”

Parameters of ECQM model

Four recent observations are used during the production of the recent version of the Electron-based Constituent Quark Model (ECQM).

1. Masses of all particles , leptons and hadrons form correlations in the mass spectrum with a common period

$$8.176 \text{ MeV} = \delta = 16m_e$$

observed in CODATA relations

The shift δm_n = 161.6491(6) keV coincides with the parameter of the tensor forces Δ^{TF} = 161 keV, found in nuclei where one-pion exchange dynamics dominates (^{18}F, ^{55}Co, ^{124}Sb, Table 1 top, Fig. 2 a,b,c), and with the radiative correction $\alpha/2\pi$ to the pion mass.

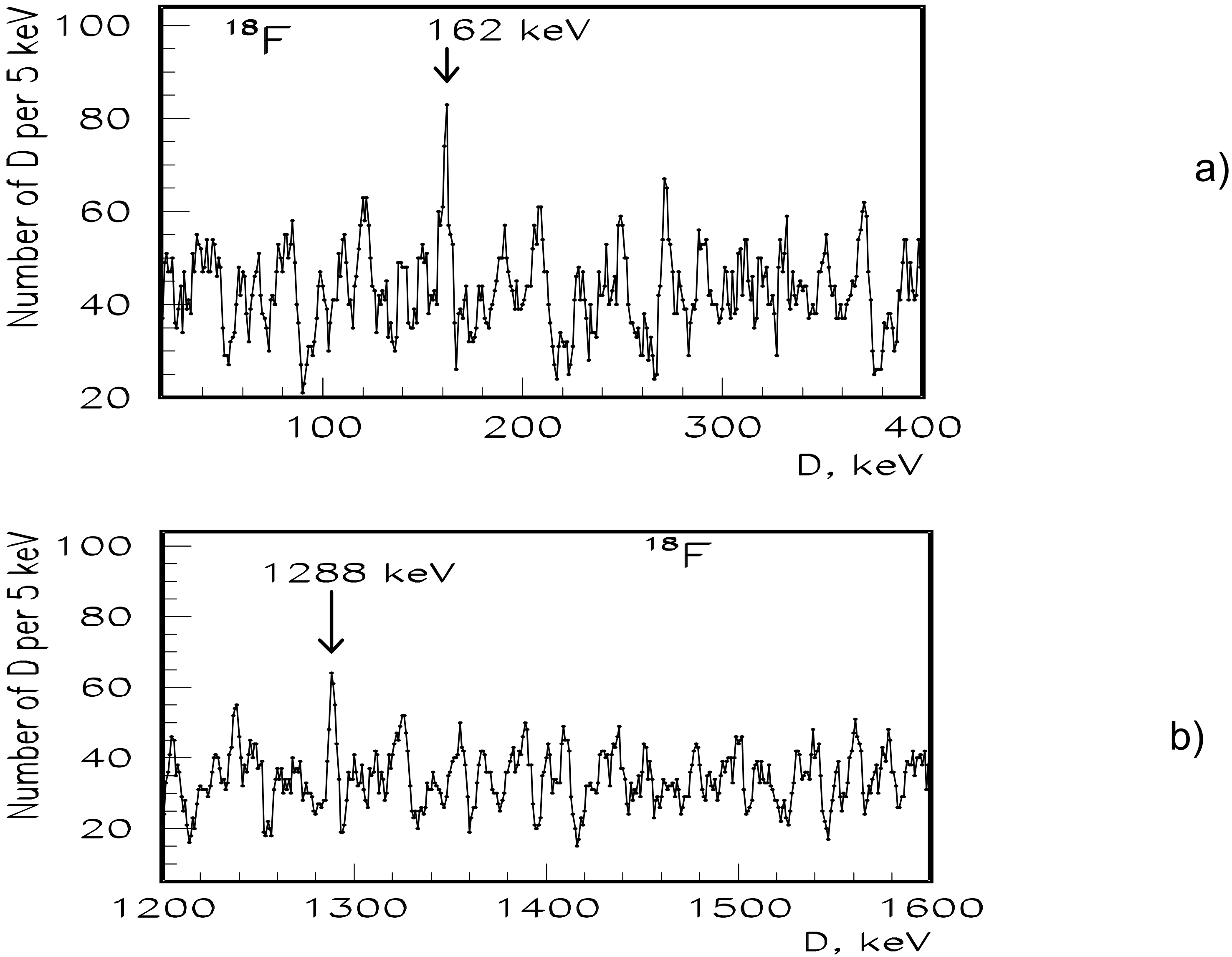


FIG. 2. Spacing distribution in levels of ^{18}F (n=372) in two different regions with maxima at 162 keV (*a*) and 1288 keV=8·161 keV *(b).*

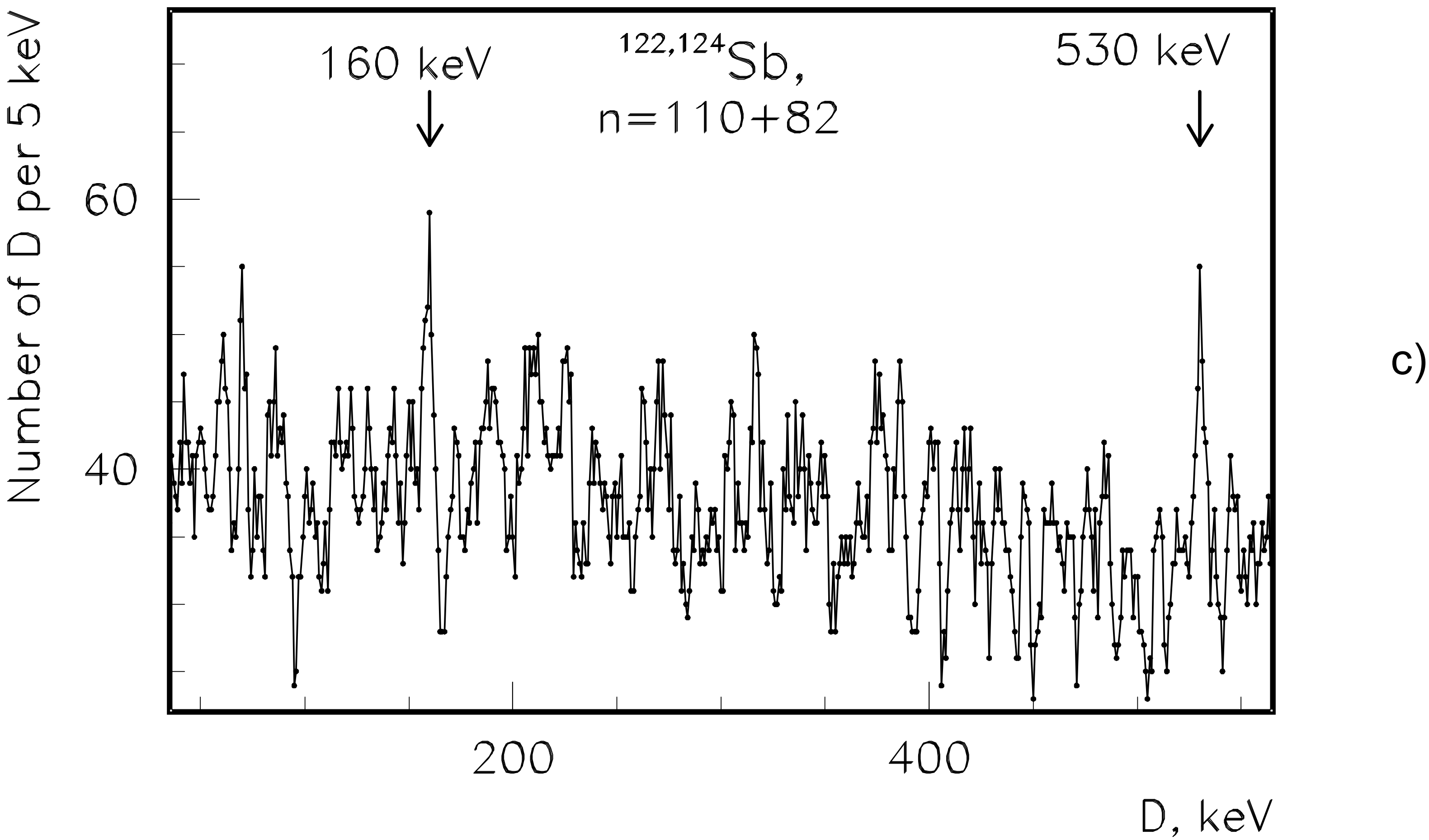
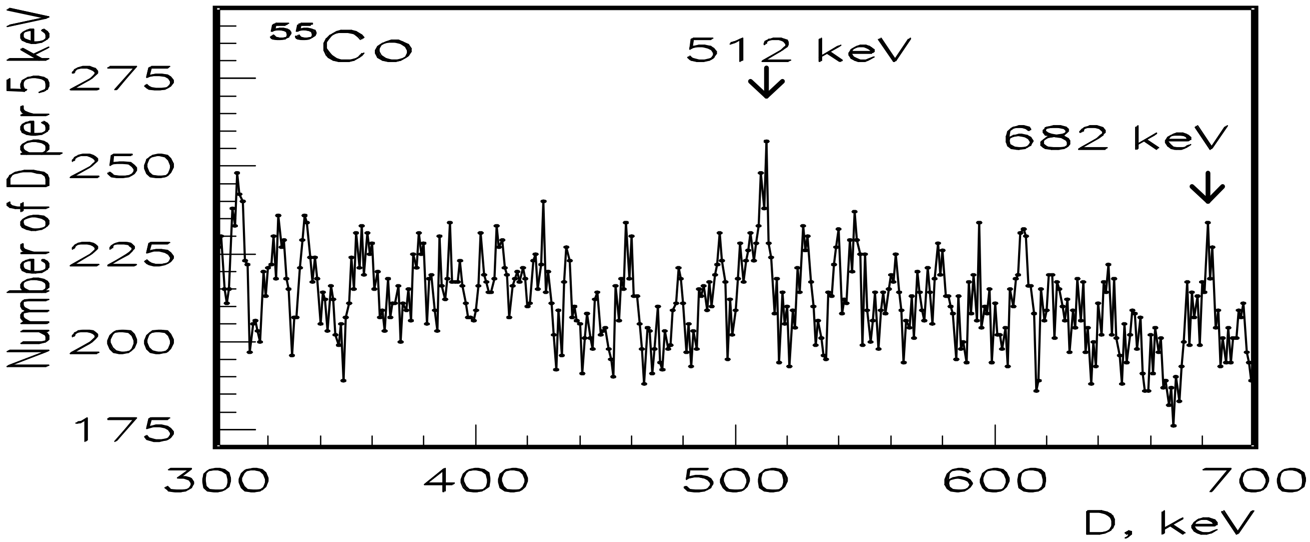


Fig. 2c. Maxima in spacing distributions in $^{122,\,124}$Sb levels.

Similar fine structure interval in CODATA relations (170 keV = $m_e/3$) connected with a shift in nucleon masses equal to electron mass and corresponding to a shift in the mass of each of constituent quarks that form nucleons, is observed in many near-magic nuclei (Table 1 bottom, Fig. 3).



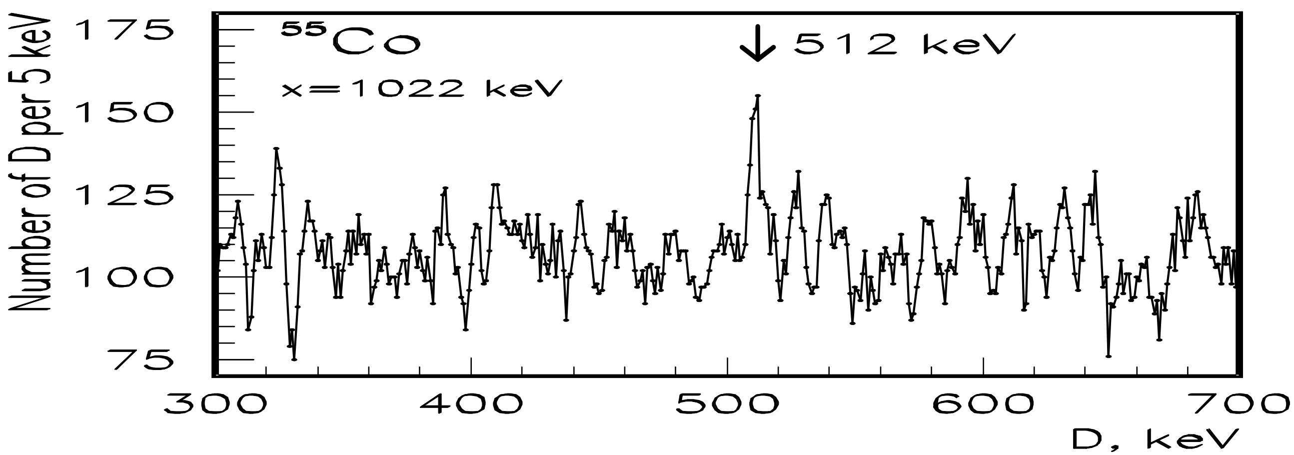
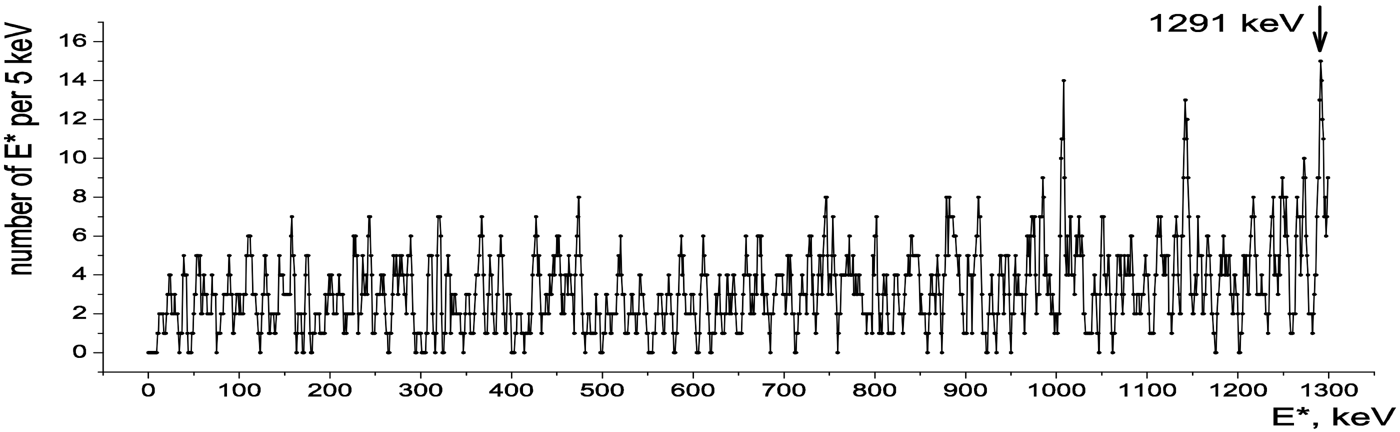


FIG. 3. *Top:* Spacing distribution in levels of ^{55}Co (ENSDF, n=372, ΔE=5 keV). *Bottom:* Distribution of intervals in the spectrum adjacent to D=x=1022 keV with a maximum at its half value 512 keV=1002 keV/2=ε_o/2 (equidistant spacing).

In Figures 4 and 5, the maxima in sum distribution of nuclear excitations coinciding with the nucleon mass splitting 1293 keV (equal to 8 intervals 161 keV) and the parameter ε_o =1022 keV=$2m_e$ (equal to 6 intervals of 170 keV) are marked with arrows and indicate integers of the fine-structure period δ\`= 9.5 keV derived from the CODATA period $16m_e$ and QED correction, and equal to

$$\delta \times \alpha/2\pi = 8.176\ \text{MeV} \times 115.9 \cdot 10^{-5} = \delta`.$$



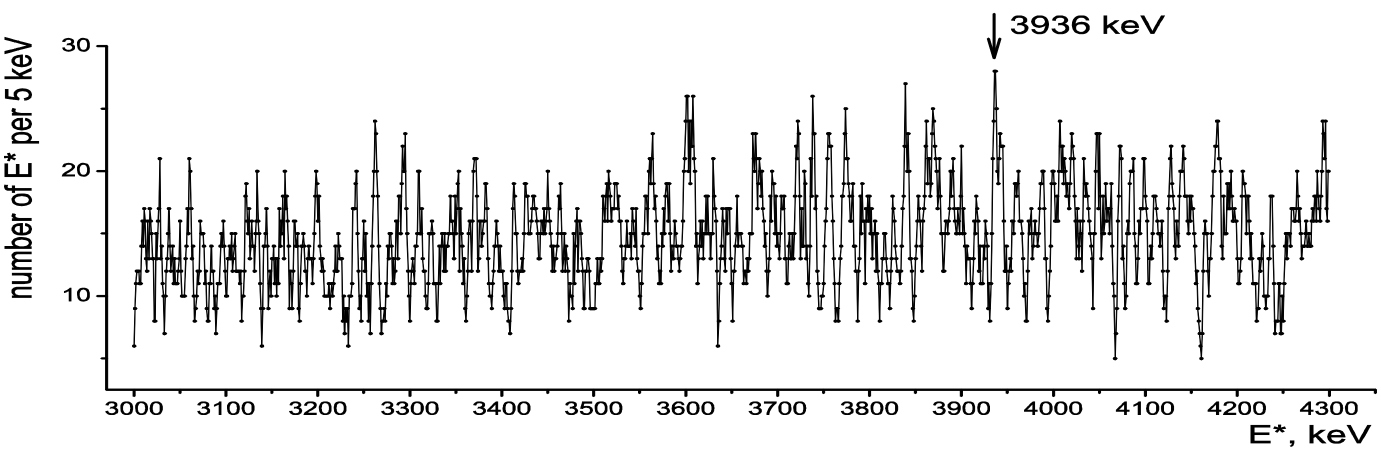
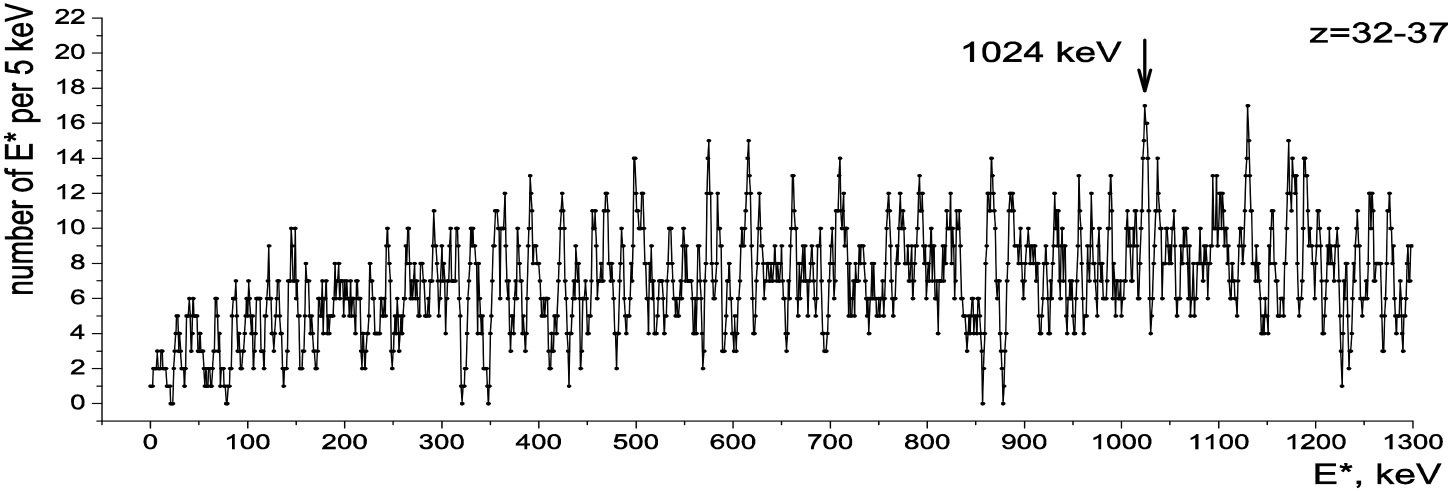


Fig. 4. E* distribution in nuclei Z=4-29 for E*<1300 keV and 3000-4300 keV. Arrows mark δm_N and 4×8×13 δ '=3936 keV.



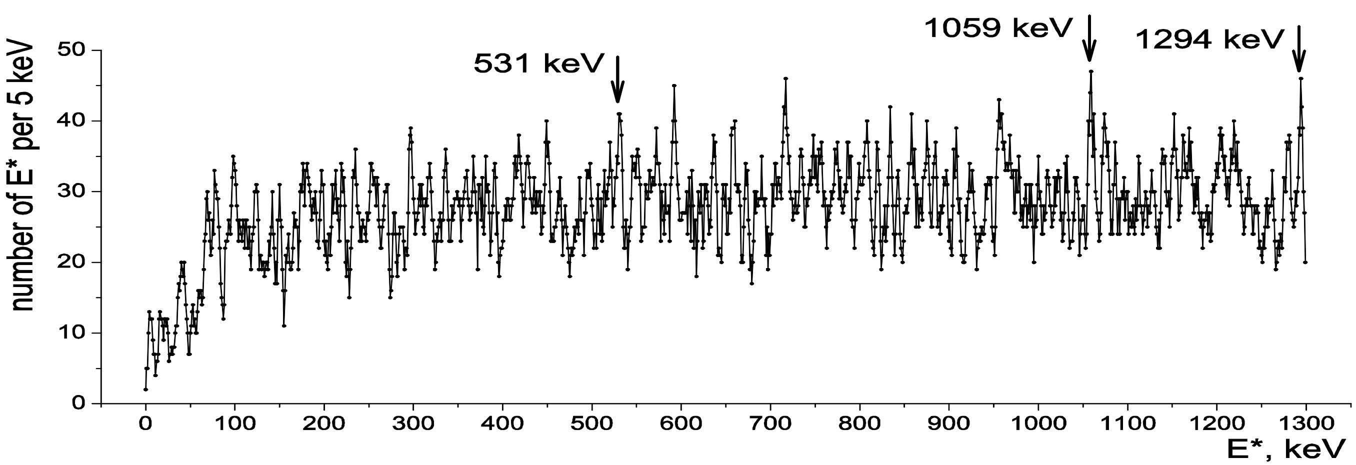


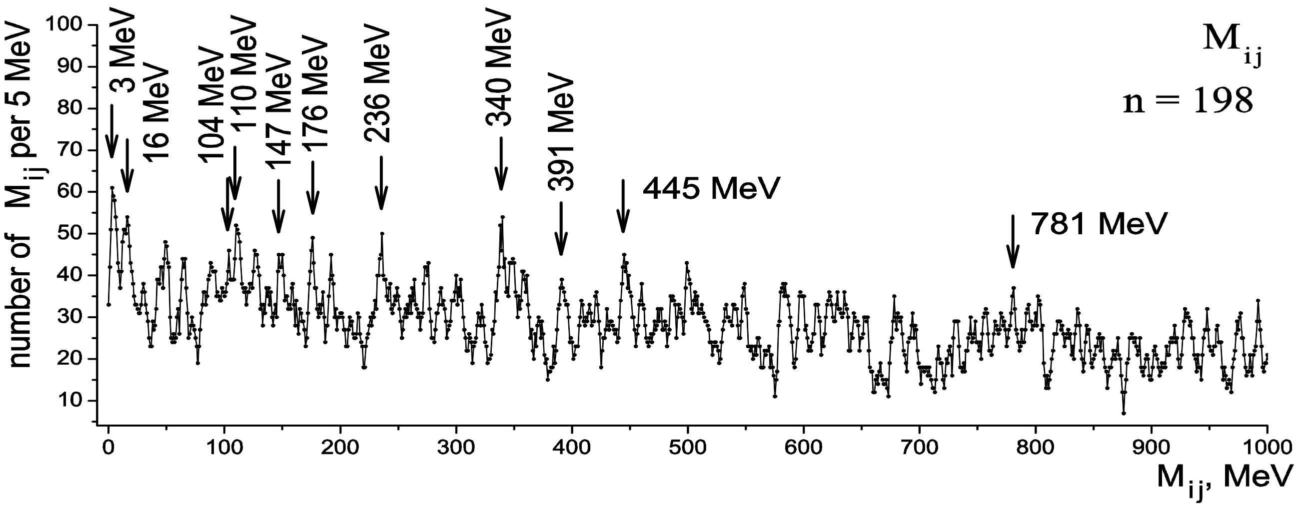
Figure 5. E* distribution in all nuclei with Z=32-35. Maximum 1024 keV=6×18 δ'. The same in nuclei Z=61-73. Maxima at 531 keV=4×7 δ ', 1059 keV=8×7 δ ' and 1294 keV =8×17 δ'= δm_N.

2. The second correlation is shown in Fig.6.

Top: ΔM distribution of all differences between all particle masses from compilation PDG-2020 (interval of the averaging 5 MeV) for the energy 0-1000 MeV. Maxima at 16 MeV = 2δ = $2 \cdot 16 m_e$, 391 MeV = $m_\omega/2$, 445 MeV = M_q, 781 MeV = m_ω. Observed maxima correspond to a presence of many stable intervals - the constituent quarks - in a spectrum of 200 particles,

Bottom:

The same for energy region 2000—4600 MeV. Maxima at 3504 MeV ≈ $8M_q = \delta^0/2$, 3962 MeV ≈ $9M_q$ and 4427 MeV ≈ $10M_q$.



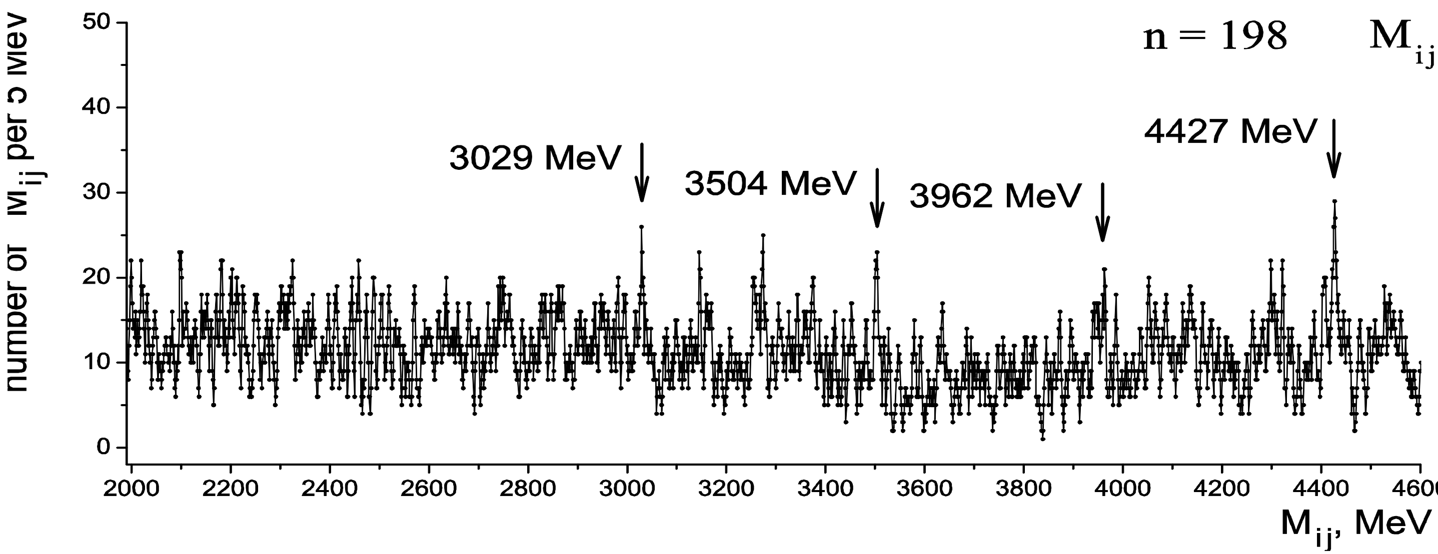


Fig. 6. Spacing distribution of all particle masses.

Masses of the fundamental fields

$M_Z = m_\mu (\alpha/2\pi)^{-1}$ and $M_{H^o} = m_e/3\ (\alpha/2\pi)^{-2}$,

and the main parameter of the ECQM and

NRCQM models $M_q = m_e(\alpha/2\pi)^{-1}$

are interconnected with symmetry motivated relations and common QED correction (Table. 2).

Table 2. Presentation of parameters of the tuning effect in particle masses (3 top sections) and nuclear data (bottom) by n·16m_e $(\alpha/2\pi)^X$ M with QED correction α/2π.

X	M	n = 1	n = 13	n = 16	n = 17	n = 18
-1	3/2			m_t=173.2		
GeV	1	$16M_q=\delta^\circ$	M_Z=91.2	M'_H=115		M_{H°=125
	1/2	(m_b-M_q)		M^{L3}=58		
0	1	$16m_e=2m_d-2m_e$	m_μ=106	f_π=130.7	m_π, Λ_{QCD}	ΔM_Δ=147
MeV	2		212	262		296
	3	NRCQM		M_q^ω=391		M_q=441
	6			m_ω=782		$2M_q$=882
	7				974	
	8			1048-1058	1115	
	9				m_c=1270(20)	
	10				1390-1407	
	12				1671-1688	
	24					3504
	27					3962
	30					4427
	60					8849
1	1	$16m_e=\delta=8\varepsilon_\circ$			$k\delta-m_n-m_e=$	170 = $m_e/3$
keV	8,1	CODATA	δm_N=1293.3		=161.651	
1	1	$9.5=\delta'=8\varepsilon'$	123	152	Δ^{TF}=161	170 (Sn)
keV	2		247 (^{91}Zr)		322 (^{33}S)	340 (^{100}Mo)
2	1,4	$11=\delta''=8\varepsilon''$	143 (As)		749 (Br, Sb)	Neutron
eV	4,8		570 (Sb)		1500 (Sb, Pd)	reson.

In the ECQM model a QED scaling factor ($m_e/M_q = \alpha/2\pi = 115.9 \cdot 10^{-5}$) is close to the ratio $1/32 \times 27 = 115.7 \cdot 10^{-5}$ and corresponds to the influence of vacuum.

Observed discreteness in masses of heavy quarks (m_{charm}, m_{bottom}, m_{top}) seen in Fig. 6, right, and masses of the fundamental fields allowed to introduce the period

$$\mathbf{16M_q = 7.06\ GeV}$$

(Fig. 6, boxed in Table 2, *top*).

3. Leptons are considered together with parameters of very successful Nonrelativistic Constituent Quark Model (NRCQM):
the pion parameters
f_π = 130 MeV, m_π =140 MeV
and constituent quark masses

$M_q = m_\Xi/3$ =441 MeV, $M^\omega_q = m_\omega/2$ = 391 MeV.

τ-lepton mass is equal to
$2m_\mu + 2m_\omega = 2m_\mu + 4\, M^\omega_q$
(see Table 3, *bottom*, Fig. 7, *top,* $m_\tau = 2m_{K^*}$) .

Table 3. Particle masses (in MeV) of different generations (families).
The relations between the masses are boxed.

Particle	Lepton	Mass	Quark Q=2/3	Mass	Quark Q=-1/3	Mass
1 fam.	e	0.511	u-quark	2.16(49)	d	4.67(48)
		m_e	$(3m_e)$	(1.53) [10]	$9m_e$	4.60
2 fam.	μ	105.658	c	1270(20)	s	93(11)
			$9m_\pi$	1256		
3 fam.	τ	1776.86(12)	t	172900	b	4180(30)
$2m_\mu$						
$+4M_q^\omega$		1776.62(24)			$9M_q =$	3959
diff.		0.24(24)	m_c-$9m_\pi$=	14(20)		

Fig. 7. The evolution of the baryon mass from $3M_q$ to Δ-baryon and nucleon masses is shown here in a two-dimensional representation: the values on the horizontal axis are given in units $16 \cdot 16m_e = f_\pi = 130.7$ MeV, remainders $M_i - n(16 \cdot 16m_e)$ are along the vertical axis in units $16m_e$. Lines with three different slopes correspond to the three pion parameters $f_\pi = 16\delta$, $m_{\pi\pm} = 17\delta$ and $\Delta M_\Delta = 18\delta$. The line with $m_\pi = 140$ MeV$= f_\pi + \delta$ (N=16+1) passes through the masses of Λ-, Ξ-, Ω-hyperons ($=8m_\pi$, $11m_\pi$, $12m_\pi$).

The stable interval in the pseudoscalar mesons $m_{\eta'} - m_{\eta} = m_{\eta} - m_{\pi\pm}$ (crossed arrows) is close to $Mq^{\Delta} = 410$ MeV $= m_d/3 = 50\ \delta$. The nucleon mass in the nuclear medium (m_{nucl}, circled point) is close to the sum of $\Delta M_{\Delta} + 6f_{\pi}$, which corresponds to the important role of the pion parameters f_{π} and ΔM_{Δ}. The values $3M_q = 9\ \Delta M_{\Delta}$ and $6f_{\pi} + \Delta M_{\Delta}$ are the initial and final stages of the nucleon mass evolution.

The mass of the charmed quark $m_c = 9m_{\pi}$ is marked on the line between the pion (π) and Ω^-.

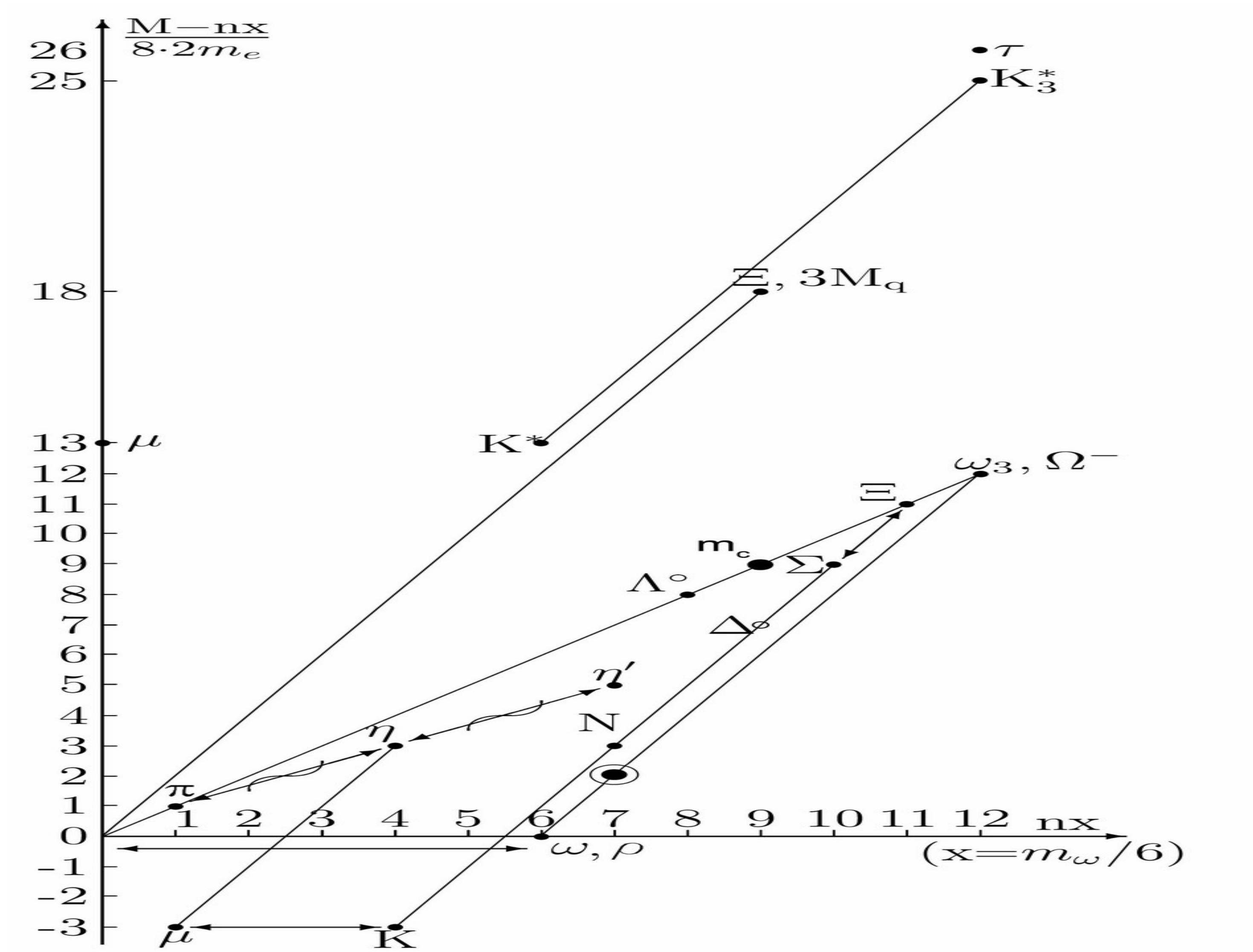


Fig. 7. Two-dimensional representation of particle masses and ECQM parameters.

4. We consider additional empirical observation of the particle mass spectrum and nuclear data, including the role of neutron resonance data in confirming the QED correction that are used for the further SM development. We show that the masses of the fundamental fields $M_Z = m_\mu\ (\alpha/2\pi)^{-1}$ and $M_H{}^0 = m_e/3(\alpha/2\pi)^{-2}$ and the main parameter of ECQM and NRCQM models, $M_q = m_e\,(\alpha/2\pi)^{-1}$ are interconnected by symmetry motivated relations and the QED correction, which can be investigated within neutron spectroscopy.

It was suggested by V.Belokurov and D.Shirkov that the small QED factor $(\alpha/2\pi)$ could be found in the electron rest mass itself.

We briefly consider here four possible connection of the obtained unexpected CODATA relations with other empirical observations.

Table 4. Comparison of the parameter α/2π =116·10^{-5} with the anomalous magnetic moment of the electron $\Delta\mu_e/\mu_e$ (top line), the parameter of parity nonconservation $\eta_{+-}/2$ (observation by J. Bernstein, second line) and with ratios between mass/energy values (lines No 1-11, 3 important relations are boxed).

No.	Параметер	Компоненты отношения	Value ×10^5
	$\Delta\mu_e/\mu_e$	$=\alpha/2\pi$-0.328 α^2/π^2	115.965
	$\eta_{+-}/2$ [54]	2.232(11)×10^{-3}/2	112(1)
	$2\delta m_\pi - 2m_e$	(81652(10) keV)/(16m_e=δ)	132(12)
1	$\delta m_\mu/m_\mu$	(23×9m_e-m_μ)/m_μ	112.1
2	m_μ/M_Z	m_μ/M_Z=91182(2) MeV	115.87(1)
3	$\delta m_n/m_\pi$	(k×m_e-m_n)/m_π=161.649 keV/m_π	115.86
4	$\varepsilon''/\varepsilon'$	1.35(2) eV/1.16(1) keV	116(3)
5	$\varepsilon'/\varepsilon_o$	1.16(1) keV/ε_o=1022 keV	114(1)
6	$(\varepsilon_o/6)/\Delta M\Delta$		116.02
7	$(\Delta M_\Delta=M_q/3)/M_{H^\circ}$	147 MeV/125 GeV	118
	δ/δ°	δ° = 16M_Z/(L = 207)=7.048 GeV	116.0
8	m_d/m_b, [1]	m_d=4.78(9) MeV/ m_b=4.18(3) GeV	114
	m_u/m_c, [1]	m_u=2.2(5) MeV/ m_c=1275(25) MeV	173(40)
9	Sb, D(187 eV)/161 keV	(373 eV/2=187 eV)/160 keV, Table 4 [12]	114
10	Pd, D(1497 eV)/1293 keV	Рис.14, внизу	115.7
11	Hf, D(1501 eV)/δm_N	^{172,176}Hf $E^*(0^+)$=1293 keV=δm_N	116.1
12	Os, D(1198 eV)/2m_e	^{178,180}Os $E^*(0^+)$=1023 keV=2m_e	117
13	Pd,Cd D(1501 eV)/δm_N	^{97}Pd $E^*(2^+)$=1293 keV	
	[67] D(1585 eV)/8m_e/3	^{even}Sn $E^*(0^+)$=4m_e	
14	Cd-XeD(1437 eV)	^{even}Cd $E^*(0^+)$ 1222 кэВ	
	[67,68] D(1723 eV)	^{even}Cd $E^*(0^+)$ 1473 кэВ	
	[67,68] D(2007 eV)	^{even}Cd $E^*(0^+)$ 1721 кэВ	
15	Te D(2375 eV)/4m_e	^{even}Te $E^*(0^+)$=4m_e	
16	N=90 D(793 eV)/4m_e/3	$E^*(0^+)$=682 keV=(4/3)m_e, .12	
17	Z=94	E*=42.5 keV D=99(2) eV	117

Unification of SM interactions

Comparison of parameters of the Standard Model and NRCQM with QED radiative correction $\alpha/2\pi$.

	Values	Mass and ratios
1	m_μ	105.659375(35)MeV
2	m_e	510.998328(11) keV
3	Ratio=m_μ/m_e	206.768
4	(L - ratio)/L	$112.08\cdot 10^{-5}$
5	$\alpha/2\pi$	$115.96\cdot 10^{-5}$
6	m_μ/M_Z	$115.90(4)\cdot 10^{-5}$
7	m_e/M_q	$115.74\cdot 10^{-5}$
8	$M_q = m_{\Xi^-}/3$	441.5 MeV=54 · 16m_e
9	$M_Z/L=M_q(1-\alpha/2\pi) - m_e$	440.5MeV=M_q^{red}
10	L = 207 = 16 · 13 - 1	

R. Feynman wrote ”The theories about the rest of physics are very similar to the theory of quantum electrodynamics: they all involve the interaction of spin 1/2 objects (like electrons and quarks) with spin 1 objects (like photons, gluons or W’s)... Why are all the theories of physics so similar in their structure?”. He suggested that future ”super-duper” model would explain simultaneously vector fields unification and representation of the QED parameters from the $\alpha=1/137$ to the $\alpha_Z \approx 1/129$.

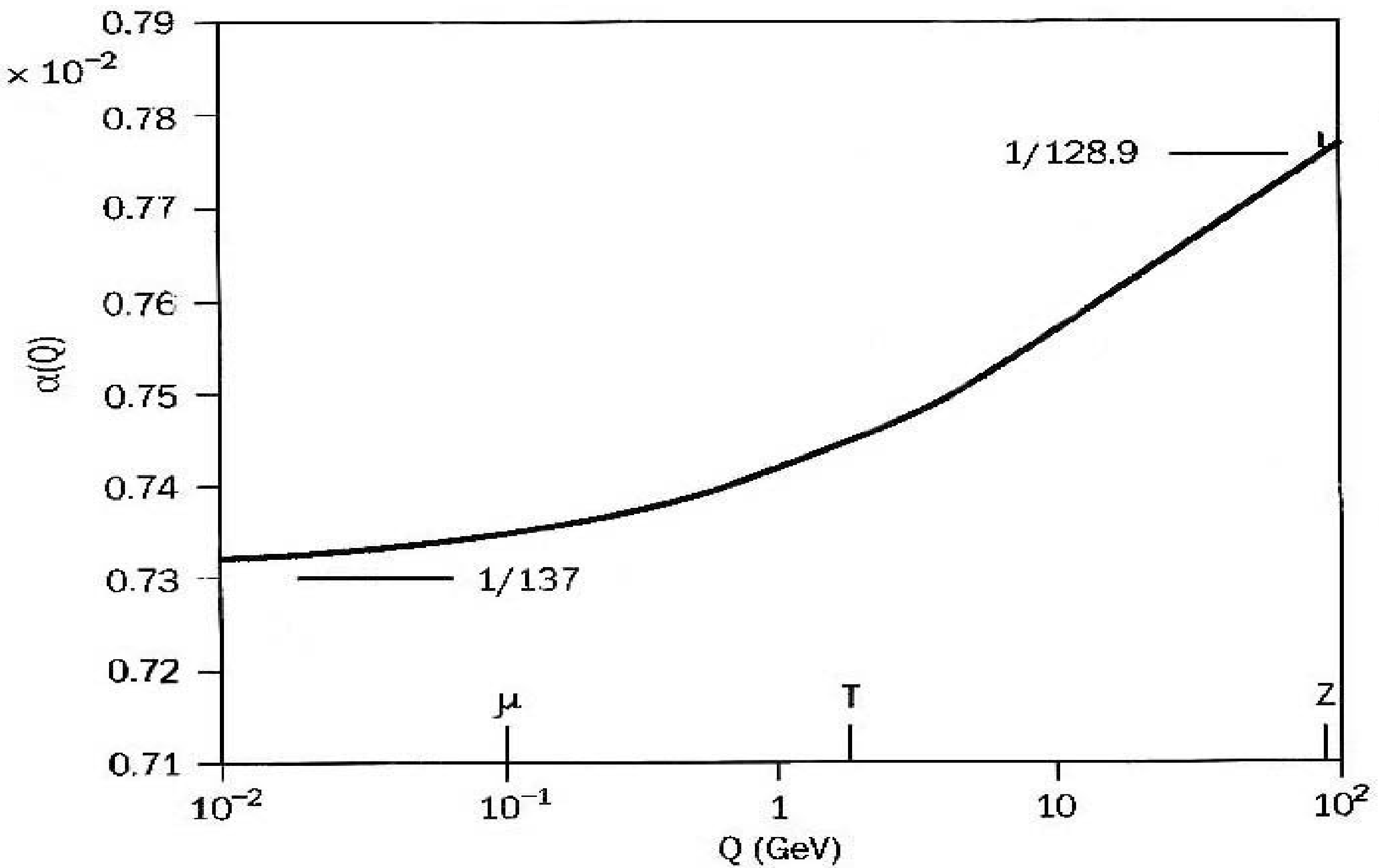


Fig. 8. Depending of the moment evolution of the QED effective charge (in square). Monotone theoretical dependence is compared with results of the $\alpha Z = 129$ measurements.

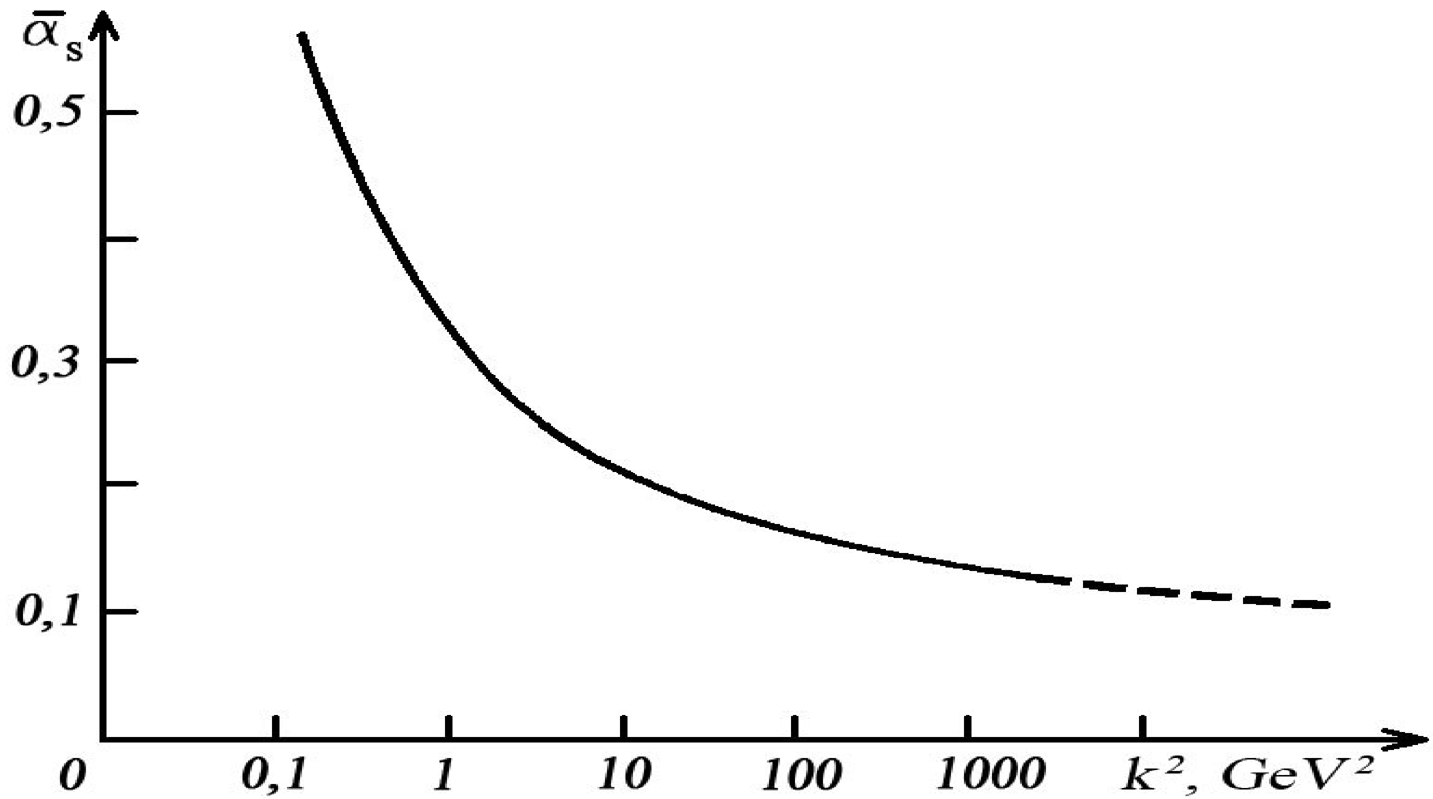


Fig. 9. Behaviour of the effective coupling α_s in QCD as a function of the squared Momentum transfer. Empirical value of QCD parameter at the energy M_Z=91 GeV is α_s=0.1181(11) close to 2/17=2δ/m_π = 0.1176. This relation containing m_π close to Λ_{QCD} was considered elsewhere.

Exactness of CODATA integer relation could mean the presence of the common general origin of all SM-interactions.

It was R. Feynman who draw attention to the common vector character of all interactions. He suggested that in the future "super-duper model" an understanding of the main parameters like a could be achieved. Relations with factor $\alpha = 1/137$ are shown in Table 2 (boxed values related as $\alpha/2\pi$).

The proximity of $\alpha/2\pi = 115.9 \cdot 10^{-5}$ to the ratio between the well-know main SM-parameters – masses of the μ-lepton and Z-boson
$m_\mu / M_Z = 115.9 \cdot 10^{-5}$ was noticed long ago.
Similar relations with QED parameter for a short ($1/M_Z$) distance $a_Z = 1/129$ can be added: the ratio between me and the pion mass
$170 keV/140 MeV = 121 \cdot 10^{-5}$, and between the pion mass and unconfirmed mass $M'_H = 116$ GeV of the possible scalar boson (twice the mass of the groping effect at 58 GeV discussed by S. Ting), namely,
$140 MeV/116 GeV = 121 \cdot 10^{-5}$, are close to
$\alpha_Z/2\pi = 123 \cdot 10^{-5}$.

CONCLUSIONS

The interconnection between the most important SM parameters starts with the electron mass and the empirical relation $M_H{}^0 = \Delta M_\Delta \times (\alpha/2\pi)^{-1} = (m_e/3) \times (\alpha/2\pi)^{-2}$, associated with properties of quantum condensate (cumulative effect in QED corrections).

The CODATA relations demonstrate unexpected stability of unique values $\delta=16m_e$ and fine structure parameters $m_e/3=170$ keV and $\delta m_N = 161$keV.

Thank you for your attention