COMBINED ANALYSIS OF NUCLEAR DATA AND PARTICLE MASSES

S.I. Sukhoruchkin, M.S. Sukhoruchkina

Petersburg Nuclear Physics Institute

Nuclear Research Center "Kurchatov Institute"

188300 Gatchina Russia

We consider here a role of the neutron resonance spectroscopy in the development of the fundamental aspects of the Nuclear Physics which are related to the Standard Model - a modern theory of all interactions. SM-development is based on the search for a "new physics", where several empirical correlations were considered together with some unanswered theoretical questions. Here we discuss the presence of "the superfine structure" in positions and spacing of neutron resonances named with this term by I.M. Frank after the works by W. Havens, M. Ohkubo, K. Ideno and others. In Fig.1a correlations in positions of neutron resonances of the near-magic compound nucleus ^{124}Sb are shown and the common period of δ''=11 eV is marked. The same discreteness with the parameter of 5.5 eV=$\delta''/2$ was found in spacing and position distributions of many heavy nuclei.

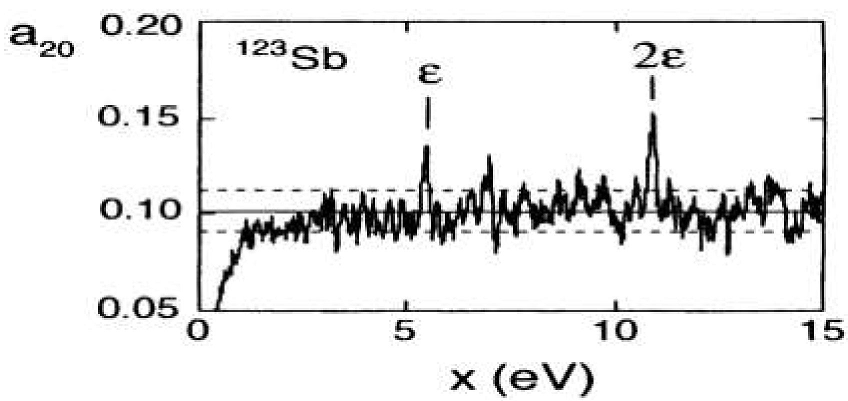


Fig. 1a. A period of ε=4ε''=5.5 eV=δ``/2 in the positions of neutron resonances in ^{124}Sb found by K.Ideno.

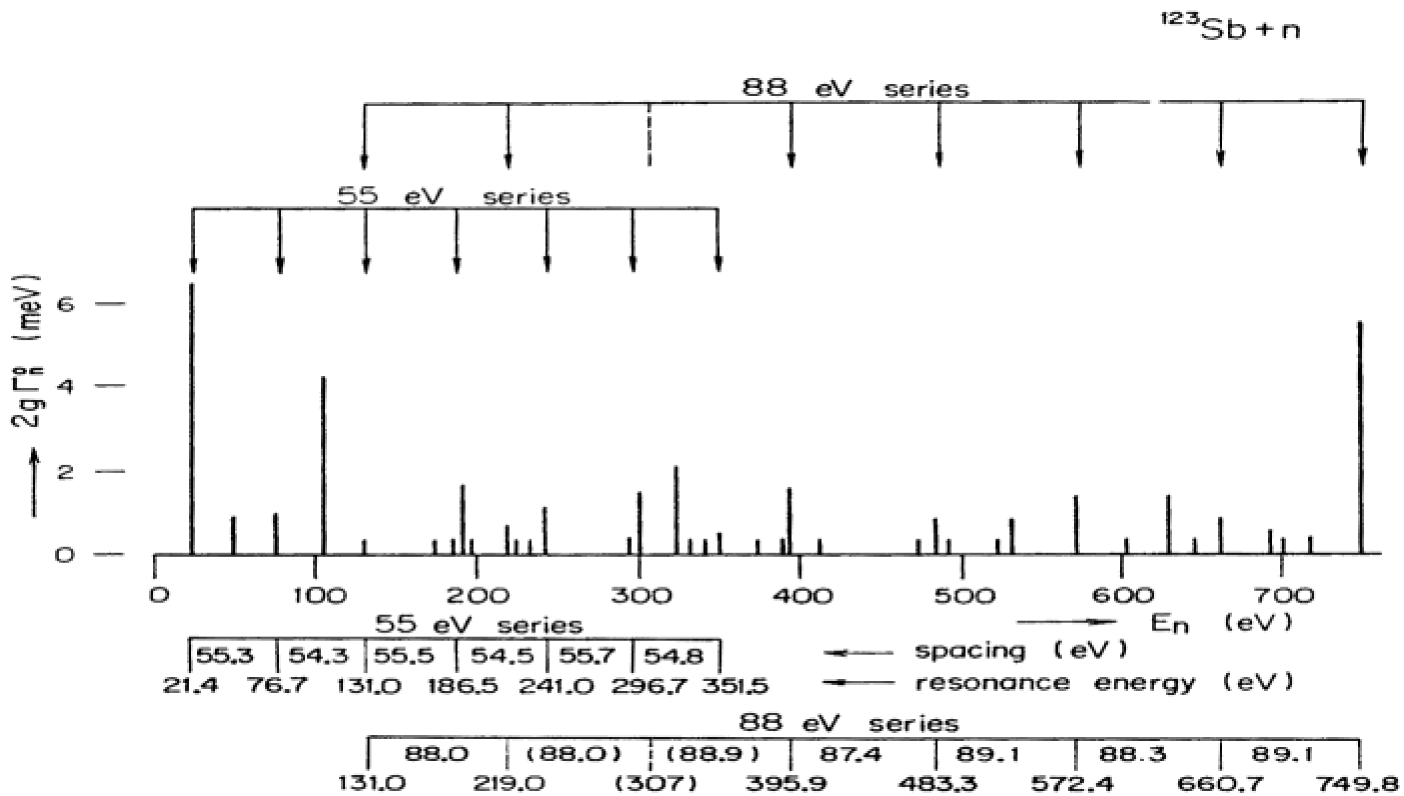


Fig. 1b. The periodicity in the positions of the neutron resonances of the compound nucleus ^{124}Sb, observed in the work by M. Ohkubo and others (JAERI-93). Resonances in the energy region 0-750 eV are given together with their neutron reduced width $2g\Gamma_n^o$ (spectroscopic factor) and two periodic series (with intervals 55 eV and 88 eV), marked with arrows (*top*), as well as with resonance energies (*bottom*). The position of the strongest resonance (*right*) with E_n=22 eV + 2×55 eV + 7×88 eV=(3+14)·44 eV=17×4δ'' is expressed using superfine structure parameter δ ''=11 eV, found by K. Izumo in a separate analysis of the same data (marked as 2ε in Fig.~1a).

Data driven science

R. Feynman described the origin of masses:

"Throughout this entire story there remains one especially unsatisfactory feature: the observed masses of the particles, m.

There is no theory that adequately explains these numbers. We use the numbers in all our theories, but we don't understand them - what they are, or where they come from. I believe that from a fundamental point of view, this is a very interesting and serious problem." And:

"Let's see how we actually calculate m. We write a series of terms that is something like the series we saw for the magnetic moment of the electron."

The main correction to μ correspond to the one-loop vertex diagram (Fig. 2, right). It was calculated in 1948 by J. Schwinger and turned to be equal to $\delta\mu=(\alpha/2\pi)\mu_0 \approx 0.00116\ \mu_0$.

Fig. 2. Feynman diagrams contributing to the electron magnetic moment.
Left: the Bohr magneton.
Right: The one-loop Schwinger correction $\alpha/2\pi=116\cdot10^{-5}$.

Table 1. Comparison of the parameter $\alpha/2\pi = 116\cdot 10^{-5}$ 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. Bernstain, second line) and with ratios between mass/energy values (lines No 1-11, 3 important relations are boxed).

No	Parameter	Components of the ratio	Value $\times 10^5$
	$\Delta\mu_e/\mu_e$	$=\alpha/2\pi - 0.328\ \alpha^2/\pi^2$	115.965
	$\eta_{+-}/2$	$2.232(11)\times 10^{-3}/2$ [6.9]	112(1)
1	$\delta(\delta m_\pi)/9m_e$	$\boxed{(\Delta\text{-}4593.66(48)\ \text{keV})/(9m_e=\Delta)}$	116(10)
2	$\delta m_n/m_\pi$	$\boxed{(\text{k}\times m_e\text{-}m_n)/m_\pi = 161.649\ \text{keV}/m_\pi}$	$\boxed{115.86}$
3	$\delta m_\mu/m_\mu$	$(23\times 9m_e\text{-}m_\mu)/m_\mu$	112.1
4	m_μ/M_Z	$\boxed{m_\mu/M_Z = 91161(31)\ \text{MeV}}$	$\boxed{115.90(4)}$
5	$\varepsilon''/\varepsilon'$	$1.35(2)\ \text{eV}/1.16(1)\ \text{keV}$	116(3)
6	$\varepsilon'/\varepsilon_o$	$1.16(1)\ \text{keV}/\varepsilon_o = 1022\ \text{keV}$	114(1)
7	$\varepsilon_o/2M_q$	$\varepsilon_o/3(m_\Delta\text{-}m_N)$	116.02
8	D(187 eV)/161 keV	(375 eV/2=187 eV)/161 keV	117
9	$(\Delta M_\Delta = m_s)/M_{H^o}$	147 MeV/125 GeV	118
10	m_d/m_b. [6.11]	$m_d = 4.78(9)$ MeV/ $m_b = 4.18(3)$ GeV	114
11	m_u/m_c, [6]	$m_u = 2.2(5)$ MeV/ $m_c = 1275(25)$ MeV	173(40)

V. Belokurov and D. Shirkov noticed that "radiative correction can be considered as reaction of the quantum vacuum on the physical particle in it...The vacuum contains fluctuations - zero oscillations - well-known property of the lowest state in the quantum theory. In QED zero oscillations consist mainly from short-lived electron-positron pairs and photon."

It was mentioned : "In general it should be pointed out that all combined set of the great number of events is the total quantity agreement with the results of calculations of the perturbation theory QED in cases when the strong interaction is negligible or if it is under the control".

From the small value of the electron rest mass (due to a lack of strong interaction) and the above mentioned notice by R. Feynman on the analogy between the corrections for the magnetic moment and for the electron mass one could expect that the component close to QED correction $\alpha/2\pi$ is contained in the electron mass itself.

Table 2. Masses of the Standard Model parameters which are in ratios close to α/2π (marked with asterisks) and comparison of their values with $9m_e$ (boxed) and 9 $m_{\pi\pm}$ (double-boxed). Proximity of the *d*-quark mass to $9m_e$ and the coincidence of the charmed quark mass m_c with 9 $m_{\pi\pm}$ are discussed.

Name	Particle, mass	Particle, mass	Particle, mass
Scalar field	H^0, 125.7(4) GeV**		
Vector field	γ, 0	g, 0	Z, 91.1876(21) GeV*
NRCQM	ΔM_Δ=147 MeV**		W,80.385(15) GeV
NRCQM	$M_q = 3\Delta M_\Delta$=441 MeV**		
Gravitation, J=2	$< 6 \times 10^{-32}$ eV		
Leptons, Q=0	ν_e <2 eV	ν_μ	ν_τ
Leptons, Q=1	e, 0.510999 MeV**	μ, 105.6584 MeV*	τ, 1776.82(16) MeV
Quarks, Q=-1/3	$\boxed{\text{d, 4.78(9) MeV***}}$	s, 95(5) MeV	b, 4.18(3) GeV***
Quarks, Q=+2/3	u, 2.2(5) MeV	$\boxed{\boxed{\text{c, 1.275(25) GeV}}}$	t, 173.21(90) GeV
Comparison with	$\boxed{9m_e=4.599\text{ MeV}}$	$\boxed{\boxed{9m_\pi=1255\text{ MeV}}}$	$9M_q$=3969 MeV

Important role of CODATA relations

We continue the analysis of results obtained with CODATA relations on the electron mass in the light of remarks by R. Feynman, V. Belokurov and D. Shirkov about a presence of $\alpha/2\pi$ component in the electron mass.
The exactly known shift of the neutron mass from $115 \cdot 16m_e - m_e$ which accounts $\delta m_n = 161.6491(6)$ keV equal to 1/8 of nucleon mass splitting $\delta m_N = 1293.3322(4)$ keV is in the ratio to the pion mass $\delta m_n/m_{\pi\pm} = 115.82 \cdot 10^{-5}$ (3-rd line in Table 1) is close to QED radiative correction $\alpha/2\pi = 115.95 \cdot 10^{-5}$.

The exact ratio $\delta m_N : \delta m_n = 8.00086(3) \approx 8 \times 1.0001(1)$ allows a representation:

$$m_n = 115 \cdot 16m_e - m_e - \delta m_N/8 \qquad m_p = 115 \cdot 16m_e - m_e - 9\delta m_N/8$$

The shift value coincides with the parameter $\Delta^{TF} = 161$ keV found in excitations of nuclei in which (according to T. Otsuka and I. Tanihata) the one-pion exchange dynamics is important (4-th line in Table 1).

It was mentioned by R. Feynman that
"The non-relativistic quark model is correct as it explains so much data.
It is for theorist to explain why."

In Fig. 3 two main parameters of the NRCQM are presented: the initial constituent quark mass $M_q = m_{\Xi}/3 = 441$ MeV shown as $3M_q$ (the initial baryon mass) on the left side of Figure and the parameter ΔM_Δ=147 MeV shown in the center $m_\Delta - m_N = 2\Delta M_\Delta$=294 MeV.

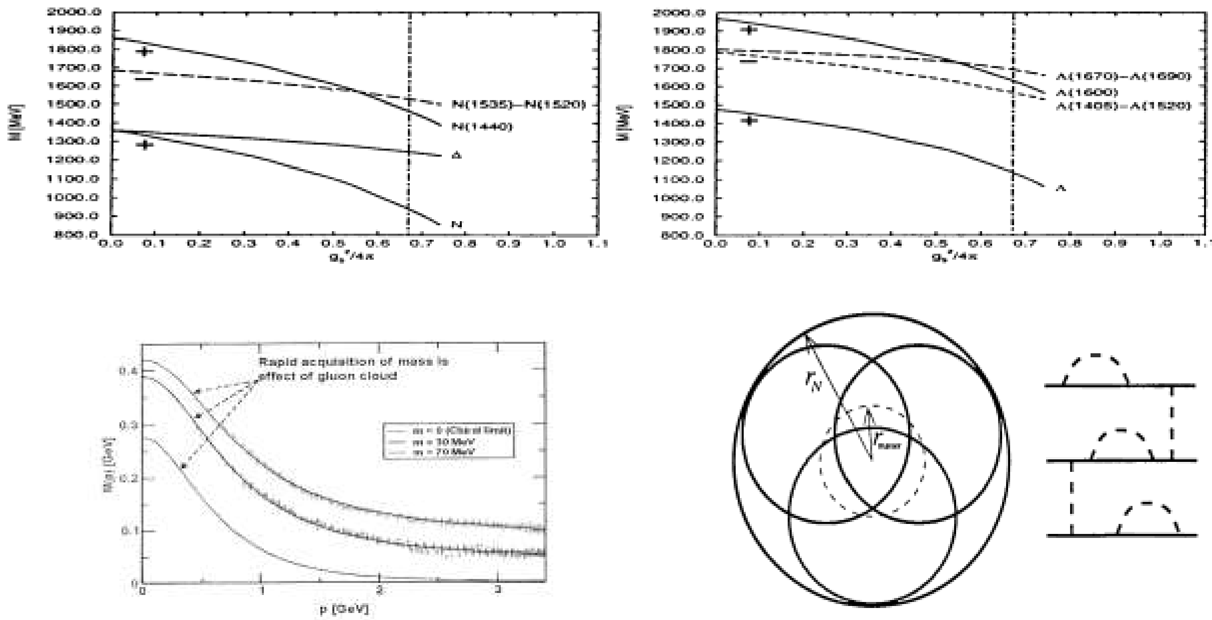


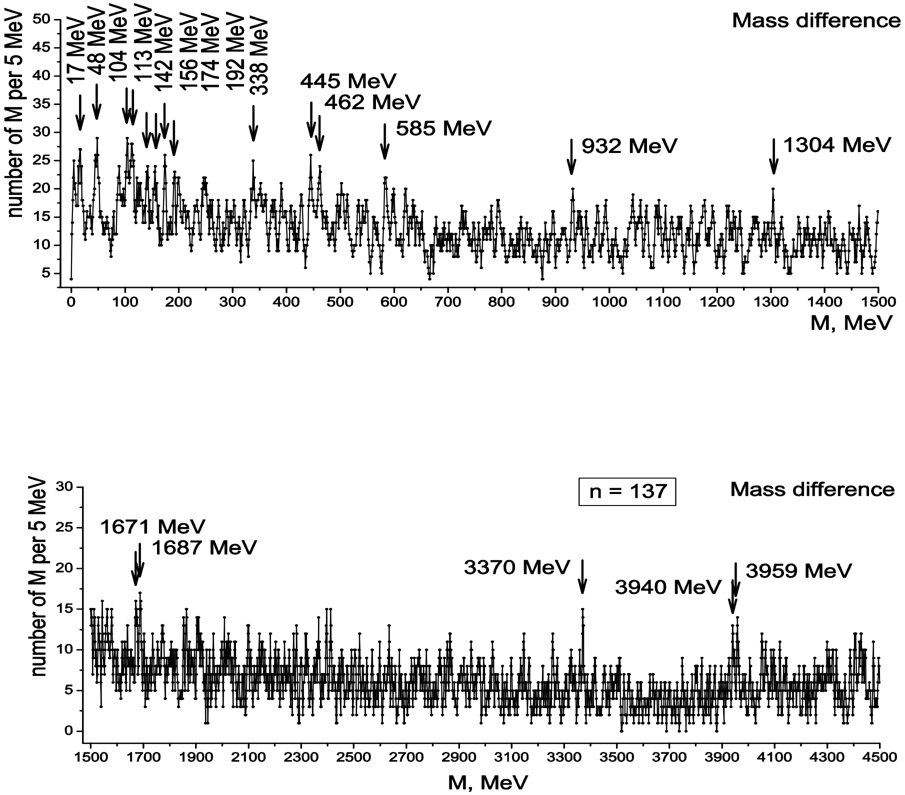
Fig. 3. *Top*: Calculation of nonstrange baryon and Λ-hyperon masses as a function of interaction strength within Goldstone Boson Exchange NRCQM Model;
the initial baryon mass 1350 MeV=3×450 MeV=3M_q is marked "+" on the left vertical axis.
Bottom: QCD gluon-quark-dressing effect calculated with DSE,
initial masses m_q=0 (*bottom*), 30 and 70 MeV (*top*).
The quark-parton acquires a momentum-dependent mass function that at infrared momentum (p=0) is larger by two-orders-of-magnitude than the current-quark mass (several MeV) due to a cloud of gluons that closes a low-momentum quark.
Right: Schematic view of nucleon structure used in NRCQM calculations (*top*), larger radius r_N and smaller r_{matter} correspond to the nucleon size and the space of the baryon matter.

Symmetry motivated relations in particle masses

Relations 1:2:17 and 1:12:24 between positions of maxima in Fig. 4, the muon and pion mass presentation (13×16-1)δ and (17×16+1) δ, maxima at ΔM=1687 MeV (n=12×17) and ΔM=3370 MeV (n=24×17) show traces of the symmetry.

Table 3. Comparison of numbers of fermions in the central field (top line) with ratios between masses m_e/M_q, m_μ/M_Z, $f_\pi/(2/3)m_t$, $\Delta M_\Delta/M_H$ and with QED parameter $\alpha/2\pi$ (central line, boxed in the bottom line is the hole configuration in 1*p* shell). One asterisk: configuration $1s^4{}_{1/2}$, $1p^8{}_{3/2}$, $1p_{1/2}$; two asterisks - configuration: new principal quantum number; filled shells - configuration - $1s^4{}_{1/2}$, $1p^8{}_{3/2,1/2}$.

N^{ferm}	N = 1	N=16	16·13-1	16·16	16·17+1	16·18
Part./param.	m_e/M_q	δ	m_μ/M_Z	f_π/M'_H	$m_{\pi^\prime}$	$\Delta M_\Delta/M_H$
Ratio	$115.9 \cdot 10^{-5}$		$115.87 \cdot 10^{-5}$	$114 \cdot 10^{-5}$		$117 \cdot 10^{-5}$
Comments			$\boxed{\text{hole in } 1p, *}$	filled shells,	**	



In Fig. 4 the distribution of values $\Delta M = m_i - m_j$ between the particle masses from PDG-2016 is presented as a histogram with the averaging interval Δ =5 MeV. It contains maxima at ΔM=142 MeV,1671-1687 MeV and 3370 MeV, close to integer numbers *k*=1, 12, 24 of the charged pion mass $m_{\pi\pm}$.

Fig. 4. Distribution of differences between particle masses ΔM in the regions 0-1500-4600 MeV.
Doublets at 445--462, 1871--1687 and 3940—3959 MeV are marked.

Conclusions

- The unusually accurate CODATA relations between the masses of nucleons and leptons and the more general Tuning effect in particle masses, in nuclear data and in parameters of the Standard Model discussed here can be viewed as part of the SM-development based on the "data-driven science" principle .
- Neutron resonance spectroscopy is part of nuclear physics where the properties of highly excited states can be investigated with very high energy resolution. The theoretical background for nuclear physics is the Standard Model with a presentation of the components:
- $SU(3)_{col} \otimes SU(2)_L \otimes U(1)_Y$.

This time we observe unexpectedly very accurate integer relations

1) between the mass shifts of the nucleons

$$\delta m_n = \delta m_N /8= \alpha/2\pi \cdot m_\pi$$

2) together with representation of the masses of nucleon, muon and

pion with an integer CODATA period $\delta=16m_e$

3) which is rationally connected with a shift of 170 keV = $m_e/3$ in each baryon quark

$$m_e/3=\Delta M_\Delta \cdot(\alpha/2\pi)=M_H{}^0\cdot(\alpha/2\pi)^2.$$

The same slogan "Data driven science" can be applied to confirmation of the Tuning effect and CODATA relations discussed here.

Thank you for your attention