# NEUTRON RESONANCES IN THE

# GLOBAL CONSTITUENT QUARK MODEL

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50 ЛЕТ НА ПИКЕ НАУКИ

Neutron resonance spectroscopy is a part of Nuclear physics based on the Standard Model (SM) as a theory of all interactions. We continue presentation at ISINN meetings the symmetry motivated and electron-based approach to the SM development.

Three empirical observation are used during production of the Electron-based Constituent Quark Model (ECQM):

1. Leptons are considered together with parameters of very successful Nonrelativistic Constituent Quark Model (NRCQM): pion parameters $f_\pi$ = 130 MeV, $m_\pi$ =140 MeV and constituent quark masses $M_q = m_\Xi/3$ = 441 MeV, $M^\omega{}_q = m_\omega/2$ = 391 MeV. Mass of τ-lepton is equal to $m_\mu + 4\, M^\omega{}_q$.

2. Leptons and hadrons are forming observed correlations in mass spectrum with a common period 8.176 MeV = δ = $16m_e$ (shown in Figure 1 from [2]) that 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.

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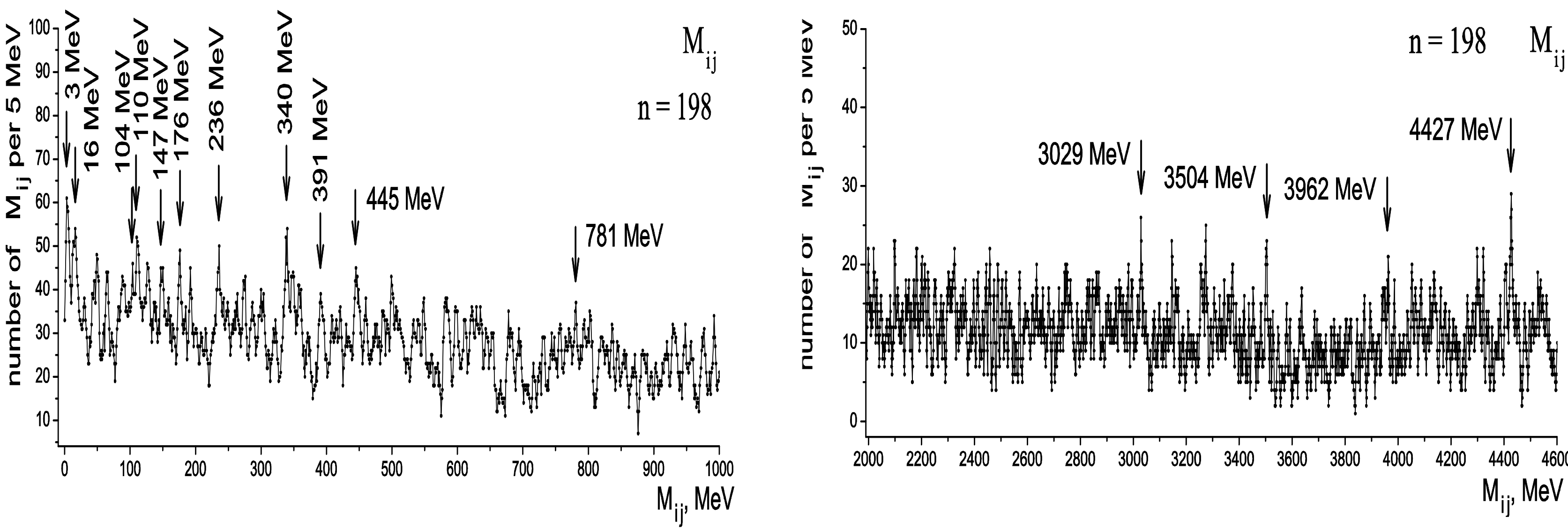
In these works, we consider additional empirical observation of the particle mass spectrum and nuclear data, including the important role of neutron resonance data in confirming the QED correction, which are used for the further SM development. We show that the masses of the fundamental fields $M_Z =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

Figure 1. *Left:*
ΔM distribution of all differences between particle masses from compilation PDG-2020 (interval of the averaging 5 MeV) for the energy region 0—1000 MeV.
Maxima at 16 MeV = 2δ =2 × 16$m_e$, 391 MeV = $m_\omega/2$, 445 MeV = $M_q$, 781 MeV = $m_\omega$ are considered in text.
*Right:*
The same for the energy region 2000—4600 MeV.
Maxima are at 3504 MeV ≈ 8$M_q$ = $\delta^0/2$, 3962 MeV ≈ 9$M_q$ and 4427 MeV ≈ 10$M_q$.



Fundamental character of similarity between correlations in particle masses and in nuclear data is based on empirical relations between masses of the nucleons and the electron (CODATA relations).

The 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 the integer $m_e$ n=115×16-1 is exactly 1/8 of the nucleon mass splitting

$\delta m_N$=1293.3322(4) keV, or $\delta m_N:\delta m_n = 8.00086(3) \approx 8\times 1.000(1)$:

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

The shift $\delta m_n$ = 161.6491(6) keV coincides with radiative correction $\alpha/2\pi$ to pion mass and with the parameter of tensor forces $\Delta^{TF}$ = 161 keV, where the one-pion exchange dynamics dominates ($^{18}F$, $^{55}Co$, $^{124}Sb$...).

Similar fine structure interval in CODATA relations, connected with the electron mass, namely, 170 keV = $m_e/3$, is observed in many near-magic nuclei.

For example, both parameters are manifested in the nucleus $^{55}Co$ with nuclear configuration of the ground state - a hole in double-magic $^{56}Ni$.

Both fine structure parameters of the CODATA relations (170 keV and 161 keV=$\delta m_N/8$, N=18 and 17 in units of the fine structure period $8\varepsilon'=16m_e\,\alpha/2\pi$ = 9.5 ,keV) are observed as stable intervals in neutron resonances and low-lying excitations.

QED radiative correction $\alpha/2\pi$ is important parameter in the Electron-based Constituent Quark Model (ECQM), which contains integer representation of particle

masses with a period of $16m_e=\delta$. The muon mass, pion parameters $f_\pi = 130$ MeV,

$m_\pi = 140$ MeV and $\Delta M_\Delta = 147$ MeV, and parameters of the NRCQM (Nonrelativistic

Constituent Quark Model) $M_q=3\Delta M_\Delta = 441$ MeV, $M^\omega{}_q=3f_\pi=391$ MeV and $\tau$-lepton mass

correspond to a unique common discreteness parameter - the period $\mathbf{16m_e = \delta}$

(with N=13, 16, 17, 18, 54=3×18, 3×16=48 and 2×13+4×48).

In the ECQM model a scaling factor ($m_e/M_q= \alpha/2\pi =116\cdot10^{-5}$), which is close to

the ratio 1/32×27, corresponds to the influence of vacuum.

Observed discreteness in masses of heavy quarks ($m_{charm}$, $m_{bottom}$, $m_{top}$) and masses

of the fundamental fields allowed introduction of the period **$16M_q$ = 7.06 GeV**.

**Analysis of neutron resonance data**

Resonance parameters that are investigated within neutron resonance spectroscopy demonstrate the same symmetry motivated relations observed between stable nuclear Intervals and in particle masses. The high accuracy in determining the neutron resonance energy, achieved by the time-of-flight method, allowed to consider together the problems of the mass spectrum (the distinguished character of the electron mass $m_e$=511 keV) and empirical correlations in nuclear data, the existence of fine and superfine structures with periods ε'=1.2 keV and ε''=1.4 eV=5.5 eV/4, equal to the first and second QED radiative corrections to the empirically found period of 1022 keV = $\varepsilon_0$ =2$m_e$ in few-particle excitations and binding energies.

We use here data for isotopes $^{233}$Th and $^{234-237}$U to check the relation

1:4:13 found earlier between stable intervals in neutron resonances

of many other isotopes [3]. Some results from performed earlier analysis

of neutron resonance data for $^{233}$Th were given also in [4].

These data for constructionally important isotopes contain the most numerous lists of resonance parameters (evaluated by F. Gunsing and L. Leal).

Thorium isotopes have 90 protons corresponding to filled $f_{7/2}$ subshell.

It was marked long ago that spacing distribution of its L=0 resonances has a clear

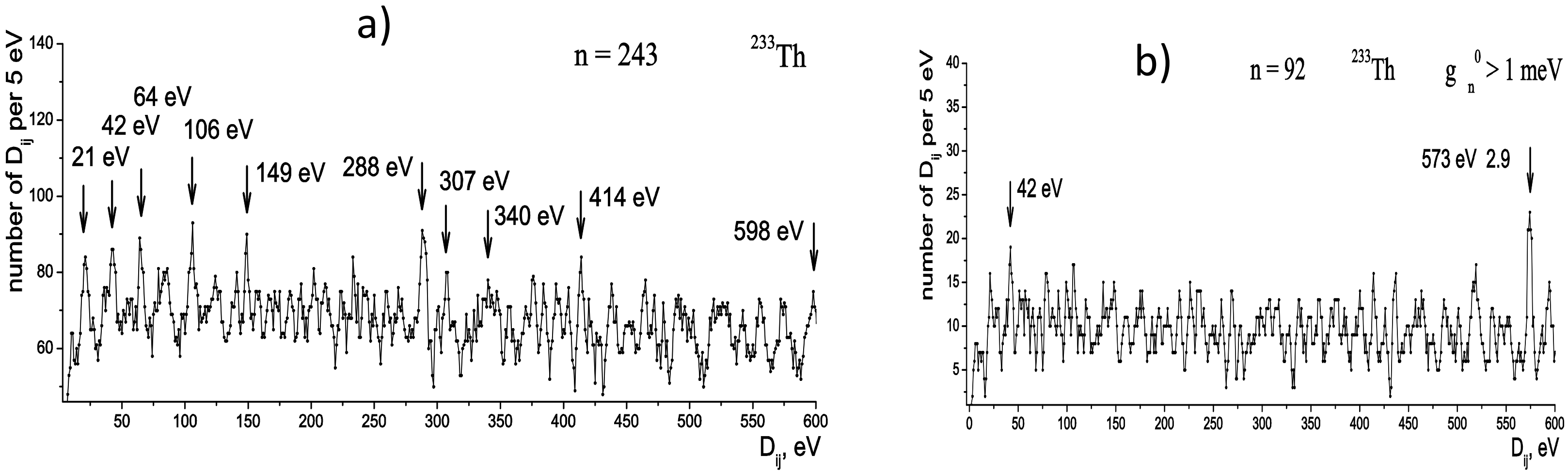
nonstatistical character. On the histogram with averaging parameter 5 eV (Fig. 2 a)

equidistancy of maxima at *k*=1, 2, 3, 5 of the estimated period 11 eV corresponds

(as *k*=288/11=26) to the strongest maximum at *D*=288 eV (marked with arrow).

Fixing all such intervals ($x$=288 eV) in the spectrum of all s-wave resonances (Fig. 2 c), one obtains maximum at the doubled value 576 eV. Such an interval corresponds to a distance between strong neutron resonances (maximum at 573 eV in Fig. 2, d, with deviation from the random level of ≈3σ, selection of resonances with reduced neutron widths greater than 1 meV).

Small maximum at 42 eV on the same distribution (Fig. 2 d corresponds to a ratio 1:13 between strong resonances (between states with relatively large single-particle component in the wave function). Similar correlations were found earlier in strong resonances of many different isotopes (Fig. 3).



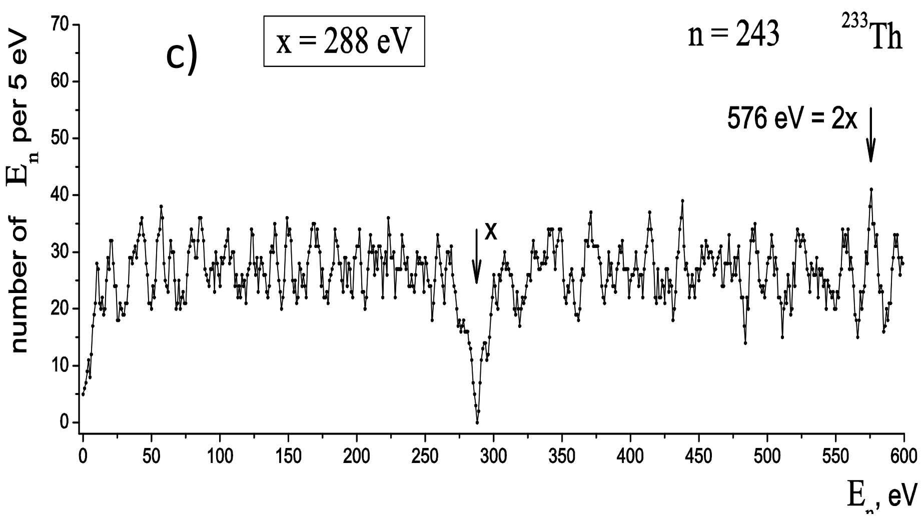




**Figure 2**. a) Spacing distribution of all L=0 neutron resonances in $^{233}$Th.

b) Spacing distribution of L=0 neutron resonances in $^{233}$Th adjacent to intervals *D*=*x*=288 eV.

c) Spacing distribution of all L=0 strong neutron resonances in $^{233}$Th.

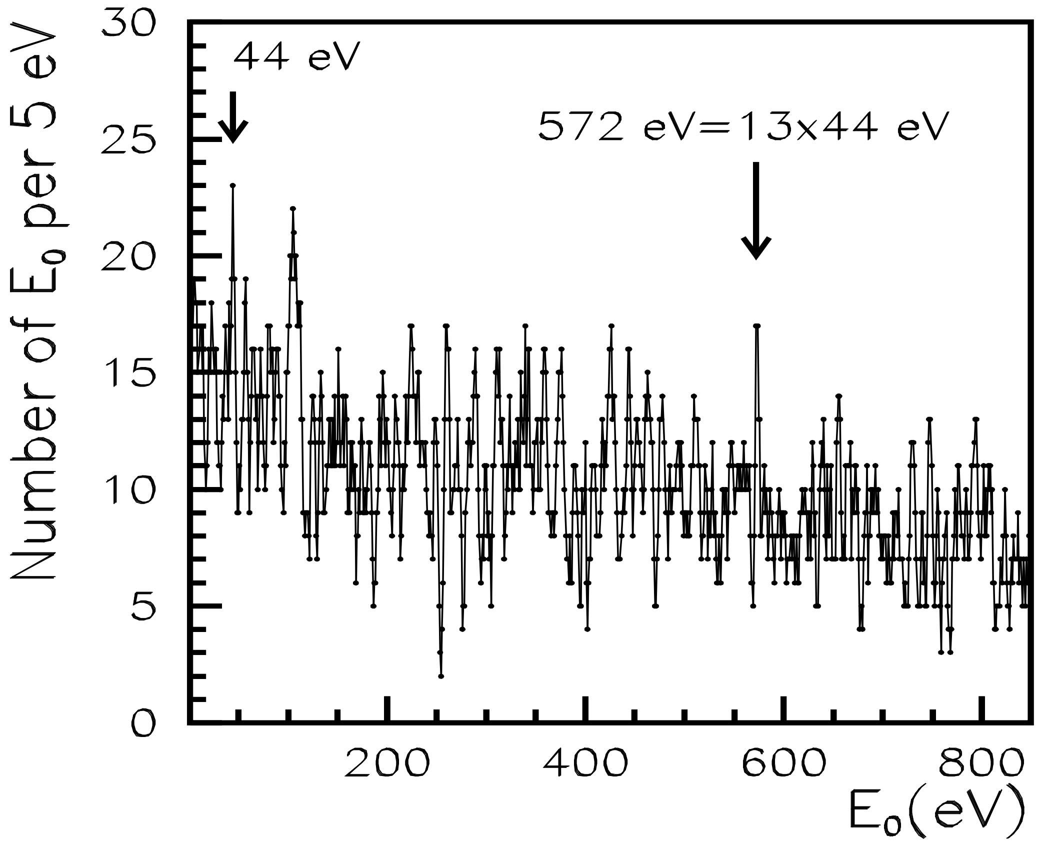
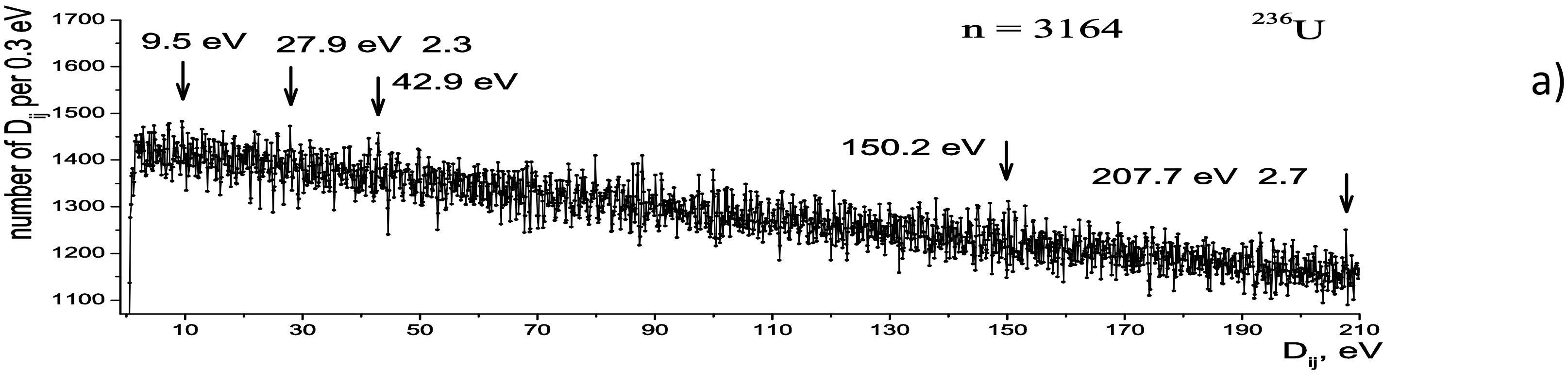



**Figure 3.** Distribution of positions of relatively strong neutron resonances of all nuclei with Z=33-56 [3]. There is strong resonance $^{233}$Th at 570 eV with $g\Gamma_n^o$ =1.1 meV, which means that neutron separation energy is correlated with the period 573 eV under consideration.

The spectrum of highly excited states of $^{236}U$ contains 3164 states with spacing distribution shown in Fig. 4a) (all states have L=0).

Neutron resonances were selected according to spin *J* (n=1438 for J=3 and n=1734 for J=4), and respective spacing distributions are given in Fig. 4 and Fig. 5.



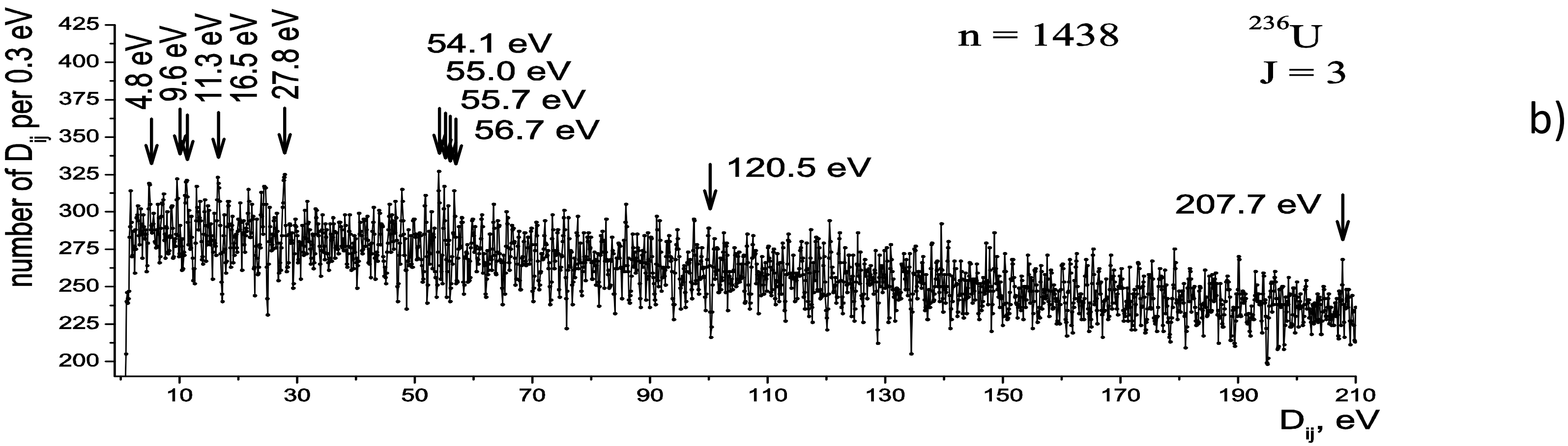




Figure 4. a) Total spacing distribution in all $^{236}U$ resonances.
b) The same for resonances with *J*=3.

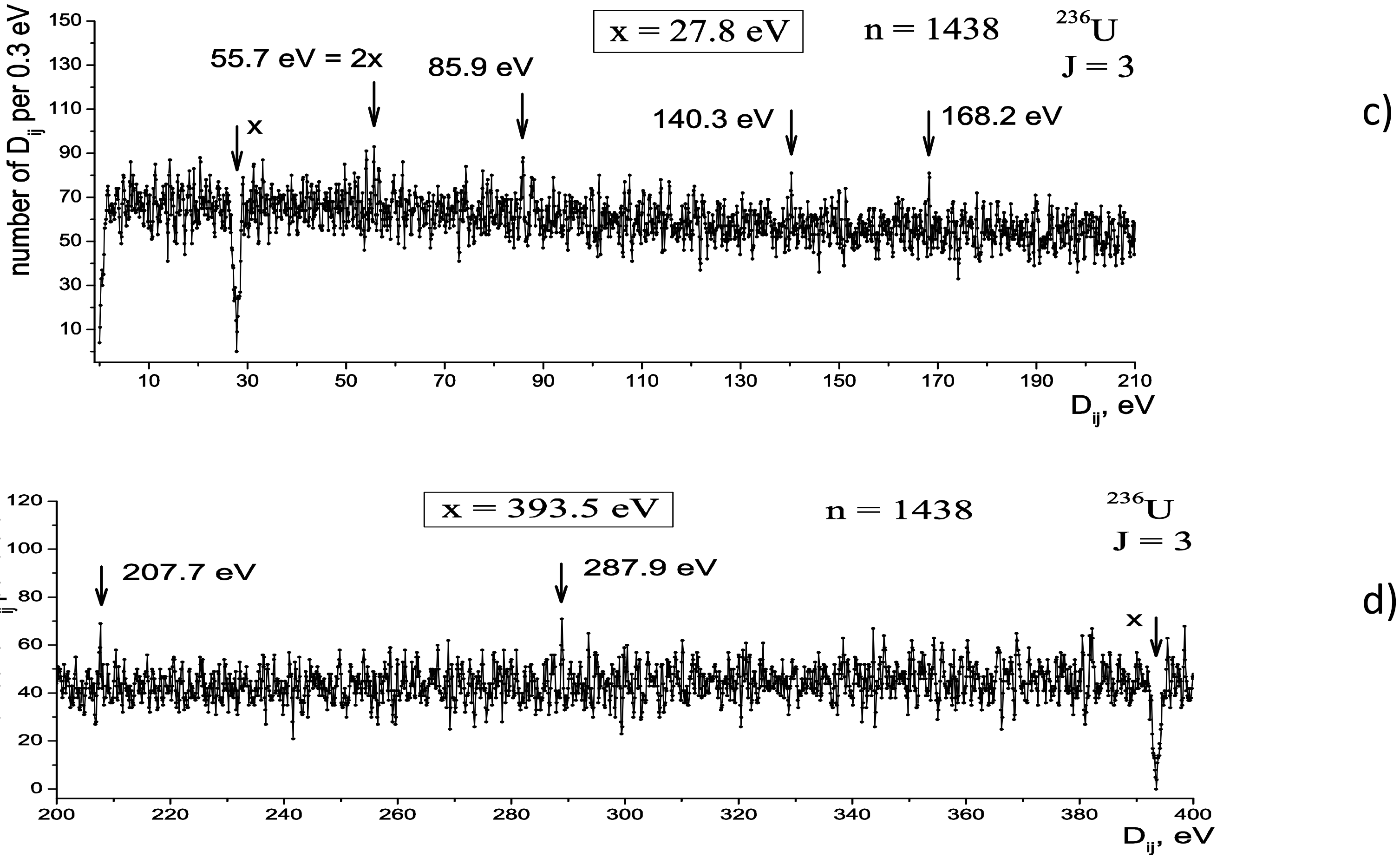



Figure 4. c) Adjacent interval distribution for $^{236}$U resonances with $J$=3, fixed interval $x$=27.8 eV.
d) The same for $x$=393.5 eV.

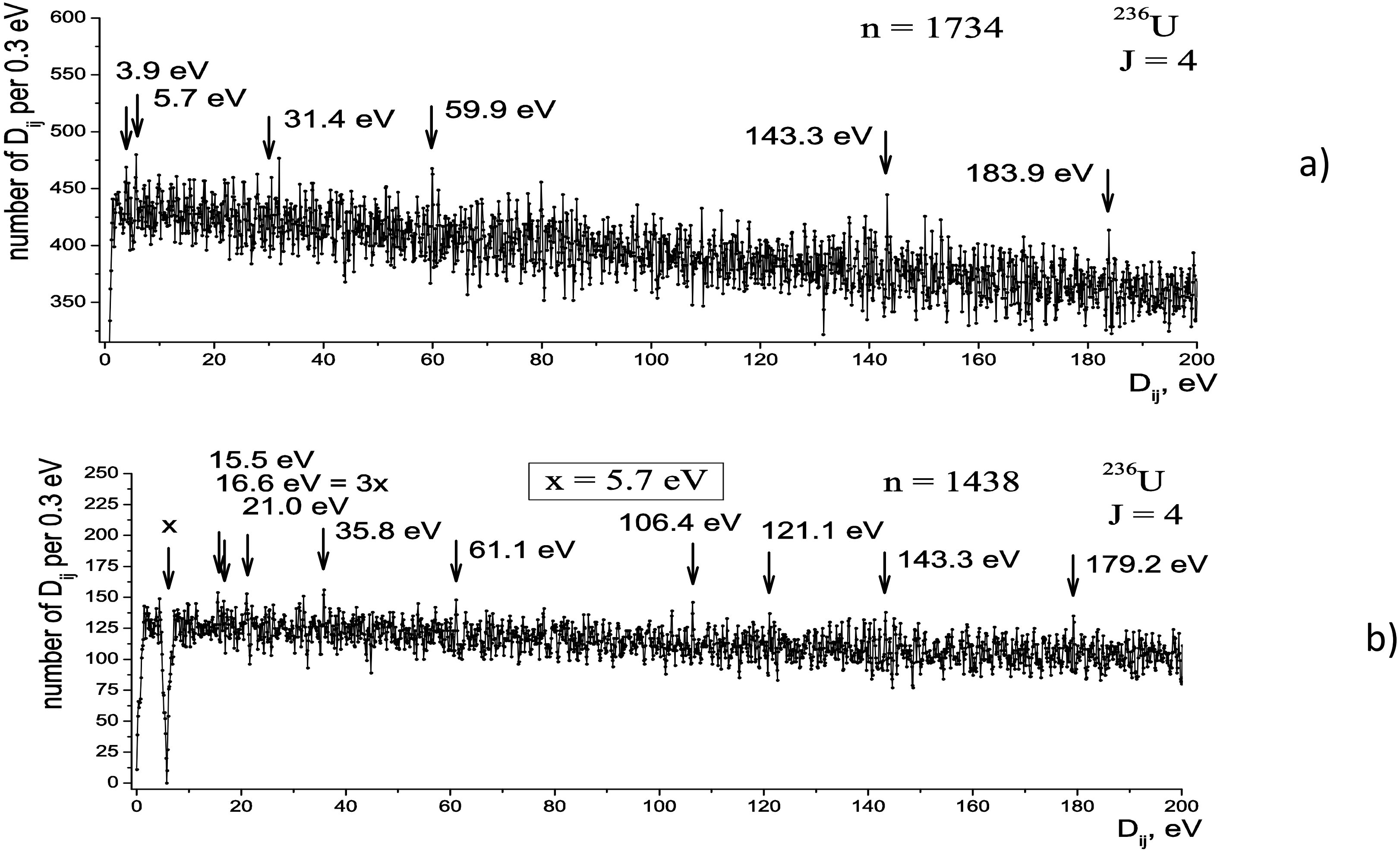
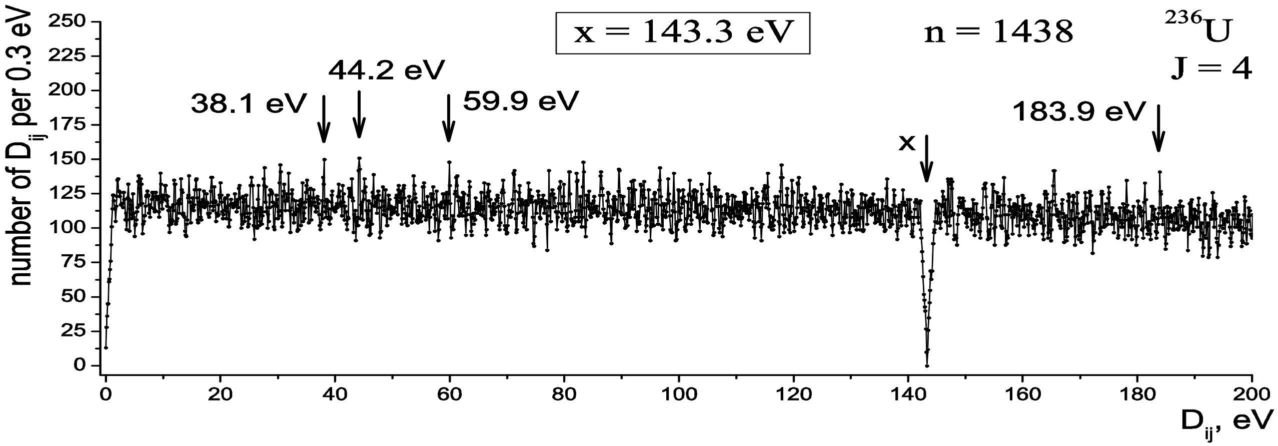
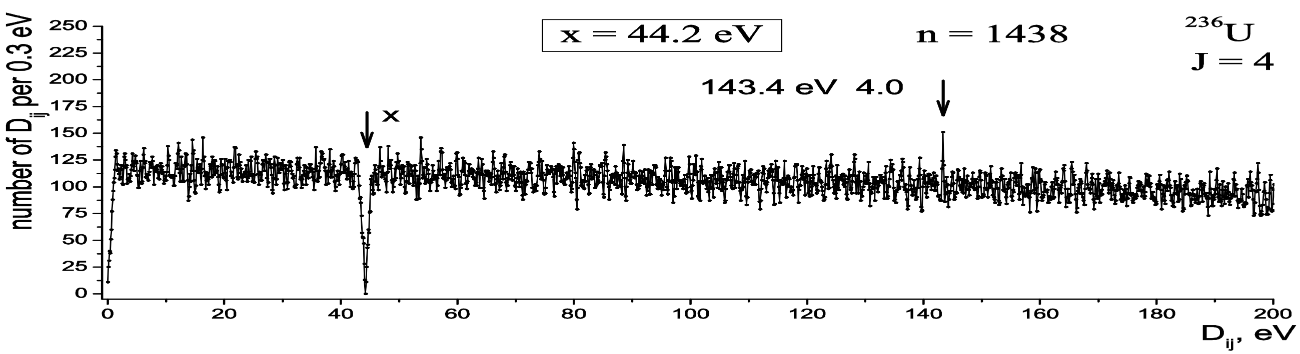



**Figure 5.** a) Spacing distribution of all $^{236}$U resonances with *J*=4.
b) Adjacent interval distribution $^{236}$U resonances with *J*=4 , fixed interval *x*=5.7 eV.




c)




d)

**Figure 5.** c) Adjacent interval distribution in *J*=4 $^{236}U$ resonances, fixed interval *x*=143.3 eV.
d) The same for *x*=44.2 eV. Deviation 4.0σ in maximum at 143.4 eV is marked. An exact ratio 13:4 is between intervals under consideration (143.4 eV and 44.2 eV).

# Conclusions

Symmetry motivated relations 1:9:13:16:17

between particle masses and stable nuclear

intervals of the few-nucleon-, fine and superfine

structures effects are considered here as an indirect

check of the ECQM model with the parameter $\alpha/2\pi$
corresponding to the QED correction.

# References

1. S.I. Sukhoruchkin, *Deviations from the statistical description of neutron level spacing distributions and stabilizing effects of nuclear shells in positions of nuclear exciting states*, in: *Statistical Prop. of Nuclei*, ed. G. Garg. Pl. Press, 1972, p. 215.

2. S.I. Sukhoruchkin, *Analysis of particle masses, nuclear data and parameters of constituent quarks*, Nucl. Part. Phys. Proc. (2021) (in press).

3. S.I. Sukhoruchkin, M.S. Sukhoruchkina, *Study of nonstatistical effects due to tensor forces. Proc. ISINN-19*, Dubna, 2011. JINR E3-2012-30, p. 308.

4. H. Schopper (Ed.), Landoldt-Boernstein New Series, Springer. Vol. **I/26A** (2015).