ISSN 1063-7796, Physics of Particles and Nuclei, 2023, Vol. 54, No. 6, pp. 1053–1055. © Pleiades Publishing, Ltd., 2023.

—Why supersymmetry is so universal?
—Supermathematics unifies discrete
and continual aspects of mathematics.
I always knew that sooner or later
p-adic numbers will appear in Physics—
André Weil

New Physics, p-Adic Nature of the Vacuum Energy, and Cosmological Constant

N. Makhaldiani*

Joint Institute for Nuclear Research, Dubna, Moscow oblast, Russia

**e-mail: mnv@jinr.ru*

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Abstract—Formal definition of the contemporary meaning of the New Physics proposed. A constituent picture of the W and H bosons considered. Mechanism for the estimation for the observable value of the cosmological constant in the supersymmetric models at finite temperatures and a connection between bosonic and fermionic statistical sums defined.

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We say that we find **New Physics** (NP) when either we find a phenomenon which is forbidden by SM in principal—this is the qualitative level of NP—or we find a significant deviation between precision calculations in SM of an observable quantity and a corresponding experimental value. Recently CDF collaboration has published [1] new measured value of the W-boson mass

$$m_W = 80.4335 \pm 0.0094 \text{ GeV}, \tag{1}$$

which is in excess of the SM prediction [2]

$$m_{\mathrm{SMW}} = 80.375 \pm 0.006 \text{ GeV} \tag{2}$$

at 7σ level.

The W boson anomaly is a signature of NP beyond the SM (BSM). Given the sizable difference in the W mass, the NP scale needs to be not too far above the TeV scale. Moreover, the NP could be at the electroweak scale if generating this discrepancy via loops. Direct NP searches at the LHC and other experiments will reveal or rule out the NP model candidates. The electroweak precision program and the Higgs precision program will also further extract the possible imprints of NP.

A decade after the discovery of the Higgs boson (H) at LHC, the true shape of the Higgs sector is still unknown. On the other hand, the Higgs sector is often extended from the minimal SM for models BSM, which can explain neutrino oscillations, dark matter and baryon asymmetry of the Universe. Therefore, unveiling the structure of the Higgs sector is quite important to narrow down BSM NP scenarios.

In the SM and its extensions the W-boson mass can be evaluated from

$$m_W^2(1 - m_W^2/m_Z^2) = a(1+\delta) = A, \quad a = \frac{\pi\alpha}{\sqrt{2}G_\mathrm{F}}, \tag{3}$$

where G_F is the Fermi constant, α is the fine structure constant, and δ represents the sum of all non-QED loop diagrams to the muon-decay amplitude which itself depends on M_W as well. We can solve Eq. (3) as

$$m_W^2 = (1 \pm \sqrt{1 - 4A/m_Z^2})\, m_Z^2/2. \tag{4}$$

To the observed value of the m_W corrseponds

$$m_W^2 = (1-\Delta)m_Z^2 = m_Z^2 - A + \ldots, \qquad \Delta = 1 - \frac{m_W^2}{m_Z^2} = 0.223. \tag{5}$$

The second solution is

$$m_{W2}^2 = \Delta m_Z^2 = A + \ldots, \qquad m_{W2} = \sqrt{\Delta} m_Z = 43.0 \text{ GeV}. \tag{6}$$

If we extrapolate the SM value of $\alpha^{-1}(m_Z)$ to electron mass scale, we find $\alpha^{-1}(m_e) = 137.0$ Coupling constant unification at $\alpha_u^{-1} = 29.0$ and scale 10^{16} GeV in MSSM [3] has a relict on the SM scale: $\alpha_2^{-1}(m) = 29.0$ at $m = 41$ GeV. The ~40 GeV constituents may be good candidates in dark matter particles. We discuss the constituent Higgs (125 GeV), W (80 GeV) and Z (91 GeV) model. We propose minimal supersimmetric constituent model with scalar ϕ and fermion ψ with valence mass m ~ 40 GeV. In this model, W and H are bound states of the valence constituents.

Let me draw the following scenario of confinement and particle production in QCD. In classical gluodynamics (in the simplest case, $A_0 = 0$ and finite energy assumption) particle-like solutions, monopoles, can not be stable due to scale (conformal) invariance. For nontrivial asymptotic A_0, we may have monopole states. In quantum gluodynamics we have not conformal invariance beyond the renormdynamic fixed points and monopoles can exist. In (one coupling constant) quantum gluodynamics we have the trivial ultraviolet fixed point at $g = 0$ and nontrivial infrared fixed point at some $g = g_c$. The Higher energy multiparticle production processes follow the following scenario: higher energy quarks and gluons (perturbatively) produce lower energy gluons and quarks until the intermediate energy-scale where running coupling constant reach the selfdual (fixed) value beyond of which monopoles start to produce. Later at the valence quark energies-scales, (at which $\alpha_s = 2$), monopoles become unstable and decay into hadrons. With exact SUSY we have cofinement by dimensional counting: superspace dimension is zero on the hadronic scale, hadrons are pointlike, color is confined inside hadrons. For SM QCD this picture indicates that at the hadronic scale we have effective SQCD, which contains scalar squarks. The monopoles play a role for seeds for primordial black holes (PBH). PBH play the role for seeds for galactics. The commonly used version of SQCD is defined in 4 dimensional space-time and contains one Majorana spinor supercharge. The particle content consists of vector supermultiplets, which include gluons and gluinos and also chiral supermultiplets which contain quarks and squarks transforming in the fundamental representation of the gauge group.

A minimal realization of the algebra of supersymmetry

$$\{Q,Q^+\} = H, \{Q,Q\} = \{Q^+,Q^+\} = 0, \tag{7}$$

is given by a point particle dynamics in one dimension, [4]

$$\begin{gathered} Q = f(-iP + W)/\sqrt{2}, \\ Q^+ = f^+(iP + W)/\sqrt{2}, \; P = -i\partial/\partial x, \end{gathered} \tag{8}$$

where the superpotential $W(x)$ is any function of x, and spinor operators f and f^+ obey the anticommuting relations

$$\{f, f^+\} = 1, \quad f^2 = (f^+)^2 = 0. \tag{9}$$

There is a following representation of operators f, f^+ and σ by Pauli spin matrices

$$\begin{gathered} f = \frac{\sigma_1 - i\sigma_2}{2} = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}, \\ f^+ = \frac{\sigma_1 + i\sigma_2}{2} = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \; \sigma = \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}. \end{gathered} \tag{10}$$

From Eqs. (7) and (8) then we have

$$H = (P^2 + W^2 + \sigma W_x)/2. \tag{11}$$

The simplest nontrivial case of the superpotential $W = \omega x$ corresponds to the supersimmetric oscillator with Hamiltonian

$$\begin{gathered} H = H_b + H_f, \;\; H_b = (P^2 + \omega^2 x^2)/2, \\ H_f = \omega\sigma/2. \end{gathered} \tag{12}$$

Fermionic part of the Hamiltonian can be used as a model for qubit in quanputing. Interaction with bosonic part may control qubit. The ground state energies of the bosonic and fermionic parts are

$$E_{b0} = \omega/2, \; E_{f0} = -\omega/2, \tag{13}$$

so the vacuum energy of the supersymmetric oscillator is

$$\begin{gathered} \langle 0|H|0\rangle = E_0 = E_{b0} + E_{f0} = 0, \\ |0\rangle =| n_b, \;\; n_f >= |n_b >|n_f > . \end{gathered} \tag{14}$$

Let us see on this toy—solution of the cosmological constant problem from the quantum statistical viewpoint. The statistical sum of the supersymmetric oscillator is

$$Z(\beta) = Z_b Z_f, \tag{15}$$

where

$$\begin{gathered} Z_b = \sum_n e^{-\beta E_{bn}} = e^{-\beta\omega/2} + e^{-\beta\omega(1+1/2)} + \dots \\ = e^{-\beta\omega/2}/(1 - e^{-\beta\omega}), \; Z_f = \sum_n e^{-\beta E_{fn}} = e^{\beta\omega/2} + e^{-\beta\omega/2}. \end{gathered} \tag{16}$$

In the low temperature limit,

$$Z(\beta) = 1 + O(e^{-\beta\omega}), \quad \beta = T^{-1}, \tag{17}$$

so cosmological constant

$$\lambda \sim \ln Z \sim e^{-\beta\omega}, \;\; \beta\omega \sim 10^2. \tag{18}$$

From observable values of β and the cosmological constant we estimate ω.

$$T = 3K = \frac{\text{eV}}{3868} \sim 10^{-4} \text{ eV}, \;\; \omega \sim 10^{-2} \text{ eV}. \tag{19}$$

In terms of Planck units, the cosmological constant is on the order of $\Lambda L_P^2 \sim 10^{-123}$.

Let as consider the following formula

$$\frac{1}{1-x} = (1+x)(1+x^2)(1+x^4)\ldots, \quad |x| < 1, \tag{20}$$

which can be proved as

$$\begin{gathered} p_k \equiv (1+x)(1+x^2)(1+x^4)\ldots(1+x^{2^k}) = \frac{1-x^{2^{(k+1)}}}{1-x}, \\ |p_k| < c(1+|x|^{2^{(k+1)}}), \quad \lim_{k\to\infty} p_k = c = 1/(1-x). \end{gathered} \tag{21}$$

This formula can be used for zeta function

$$\begin{gathered} \zeta(s) = \sum_{n\geq 1} n^{-s} = \prod_p (1-p^{-s})^{-1}, \quad \mathrm{Re}\ s > 1, \\ |0|_2 = 0, \ |2^n|_2 = 2^{-n}, \end{gathered} \tag{22}$$

when $x = x_n = p_n^{-s}$. If we take corresponding expression as definition for zeta function we will have zeros at $s = (2k+1)\pi i/\ln(p_n)$, p_n is prime, k is integer number, $|p^n|_p = p^{-n}$ is p-adic norm. The formula (20) reminds us the boson and fermion statsums

$$Z_b = \frac{\sqrt{x}}{1-x}, \ Z_f = \frac{1+x}{\sqrt{x}}, \ x = \exp(-\beta\omega) \tag{23}$$

and can be transformed in the following relation

$$Z_b(\omega) = Z_f(\omega)Z_f(2\omega)Z_f(4\omega)\ldots \tag{24}$$

Indeed, [5]

$$\begin{gathered} Z_b(\omega) = \frac{\sqrt{x}}{1-x} = x^{a/2} Z_f(\omega)Z_f(2\omega)Z_f(4\omega)\ldots, \\ a = 1 + (1 + 2 + 2^2 + \ldots) = 1 + \frac{1}{1-2} = 0, \\ |2|_2 = 1/2 < 1. \end{gathered} \tag{25}$$

By the way we have an extra bonus! We see that the fermi content of the boson wears the p-adic sense. The prime $p = 2$, in this case. Also, the vacuum energy of the oscillators wear p-adic sense.

CONFLICT OF INTEREST

The author declares that he has no conflicts of interest.

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