On One-loop RG Analysis of SUSY $SU(5)$ and E_6 models

V. Beylin, V. Kuksa, G. Vereshkov

Division of Theoretical Physics,Institute of Physics, Rostov State University
Stachki,194, Rostov-on-Don, 344090, Russia

Abstract

Renormgroup equations at the one – loop level for SUSY $SU(5)$ and E_6 models have been analyzed in a special universal form. It is shown that information on spectra of dynamical scales can be extracted from these equations due to known experimental data on couplings at m_Z scale. There are various sets of scales for considered models. These sets can be separated experimentally because of different effects induced by production and decay of nonstandard fermions in the SM extensions.

1 Introduction

Now there are no experimental facts that contradict the SM predictions[1]. It is necessary, however, to note, that there is a good agreement of the theory with experiment if we consider the effects at a tree level with an account of LO and NLO loop corrections only. For purely loop processes, in particular, for phenomena induced by FCNC [2], the situation is ambiguous: at present the errors of measurements are not small, and besides in some cases the role of the non-perturbative corrections is important. Thus these contributions can be accounted for with the help of the Sum Rules or some other model way [3].

The priority of modern experimental high-energy physics is detection of Higgs boson, or, more precisely, scalar particles with electromagnetic and weak couplings. Thus, it is necessary to compare properties of these scalar objects with the SM predictions. From the recent measurements the direct limitation on Higgs boson mass is known [1], and from the fit of electroweak data with account of radiation corrections the prediction for the only scalar Higgs boson of the one-doublet SM follows.

There are three conceptual problems of the SM, which solution can be obtained only beyond this theory. The first one is a problem of Higgs fields genesis. Within the framework of the SM these fields are introduced as a separate sector, their properties are fixed phenomenologically, while the properties of gauge and matter fields are determined uniquely. Nevertheless, there are grounds to suppose the status of scalar fields as fundamental, and also to interpret Higgs vacuum condensate as a classical component of a scalar field. The concept of spontaneous breaking of gauge symmetry is also of fundamental nature. These ideas are waived off in composite models, where the compound scalar particles have the properties different from fundamental Higgs bosons. For this reason the problem of future experiments is not only to find these particles, but also to establish a degree of agreement of their properties with the SM predictions. Preserving the fundamental status of the Higgs fields, the problem of their genesis can be solved in the supersymmetric SM generalizations. In this case, if we place super-Higgs and matter superfields or supergauge fields in one supermultiplet, they are treated on the same footing. The problem of dynamics will be finding the conditions that lead to appearance of the Higgs condensate.

One more problem of the SM is induced by the special status of very light neutrino with $m_\nu \approx 0$. Solution of this problem is uniquely determined by an answer to the problem of existence of a right chiral neutrino state. If such states are formally included in the SM when the bi-fundamental representation of $SU(2)$ is absent in the Higgs sector, the neutrino remains with zero mass. However, there remains a problem whether the leptonic charge is conserved in such model. If it is so, there is no Mayorana term in the model to form the right neutrino mass. Then the Dirac masses will be obtained as a result of the standard Higgs shift. In this case there remains unclear, why the Yukava couplings are so small? It is possible to avoid introducing groundlessly small couplings in a model with large Mayorana masses for right neutrino and leptonic number violation. Then the small masses of the standard neutrino result from mixing of very light and very heavy neutrino states. As a result, there are some questions in such models: what is the origin of right neutrinos and what is the scale of their masses? Besides, there is no answer and to a problem whether these right neutrinos will participate in new fundamental gauge interaction.

It should be noted that the problem of special neutrino status is naturally solved in models, where two requirements are fulfilled simultaneously.

First, the extra neutrino fields should be contained in the same irreducible representations of a symmetry group of the model, as the usual matter fields. This means that the symmetry group should be that of the extended SM. Second, the large neutrino masses should automatically appear when initial symmetry is broken to the SM symmetry. Problems of Higgs boson and right neutrino genesis can be considered simultaneously within the framework of SUSY models [4, 5].

The objects of these models are irreducible representations having the properties:

1) the spinor components of the same supermultiplet contain besides the known matter fields new fields of extra neutrino;

2) in this supermultiplet, among scalar components there are superpartners of known matter fields and Higgs fields that are responsible both for the spontaneous electroweak symmetry breaking and higher symmetries;

3) the scalar partners of extra neutrino form the Higgs condensates.

As for a problem of three quark - lepton generations genesis, within the framework of the same logical scheme it is possible to guess that there is a model at some high energetic scale, and all known generations are included in one of its irreducible representation. It is known also that solution of the SM conceptual problems is possible in the superstring theory, or, more exactly, in the low-energy (as compared to the Planck scale) models of superstring sector with zero mass [6]. Within the framework of realistic heterotic superstring theories [6] it is meaningful to discuss only two groups $SO(32)$ and $E_8 \times E'_8$ and it is necessary to include zero-mass sector in some of their subgroups. These subgroups have equal rank and identical number of gauge bosons $N_B = 496$ or $N_B = 248 + 248$ [6, 7].

The group $E_8 \times E'_8$ is more convenient for consideration of low-energy reductions. Discussion of this gauge symmetry in superstring theory is present in literature [7, 8]. At the Planck scale, there is a compactification of extra dimensions, thus one group E_8

breaks to E_6. Below this group is referred to as $N = 1$ SUSY GUT theory. The number of quark generations in the theory is determined by topology of compactified space. Other E_8 group that remains unbroken describe interacting fields in the "shaded" world. It should be noted that at the $E_8 \times E'_8$ level there is a symmetry of field structure between the "shaded" and real worlds, and consequently of the interactions. This symmetry will be broken, if the numbers of generations in both patterns are different.

Thus, the problem of existence of three generations is connected with existence of a symmetry between "shaded" and real worlds and also supergauge transformations group that is predicted by superstring theory and finiteness of the theory in 4-dimension space-time. In any case, now it seems clear that at high-energy scale there is some extended theory, possibly based on superstring ideas, so at a lower scale there should exist a SUSY GUT. For every choice of specific SUSY realization, it is necessary to analyze the corresponding spectra of scales. The question of the scales for new objects in the generalized theory is connected with the other problem: is it possible to find a theory where these scales are fixed by some clear dynamical principles? The known value $M_{SUSY} \approx 1$ TeV that is most optimistic for the experiment has as an argument stability of the unification scheme [5]. For superfields and Higgs bosons this scale is preferable in the framework of the natural and minimal superextension of the SM — in the MSSM or SUSY $SU(5)$ as a more general theory [5]. This scenario should be verified in the nearest future at LHC. Unfortunately, this supersymmetric scheme cannot solve any of the above mentioned SM problems and, moreover, there is no answer to the question whether this model can fix the scale of new physics unambiguously? For an answer we consider the renormgroup one-loop analysis for SUSY $SU(5)$.

2 Energetic scales for SUSY $SU(5)$ in one-loop approximation

Let us remind the content of SUSY $SU(5)$ dynamical families, that are main objects both of the theory and experimental searches. Besides the three standard generations of SM fermions and bosons, the set of the states in the model contains three generations of superpartners for quark and leptons $(\tilde{q}, \tilde{l})$; chargino, neutralino and gluino $(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{G})$; 5-plet with singlet quark state D and an extra heavy lepton — higgsino $(D, \tilde{h})$; 5-plet with superpartner for singlet quark and Higgs $(\tilde{D}, H)$.

Now we use one-loop RG equations in the form

$$\alpha_i^{-1}(\mu) = \alpha_i^{-1}(\mu_0) + \frac{b_i}{2\pi} \ln \frac{\mu}{\mu_0} \tag{1}$$

Let us fix some known experimental results [1] at the scale $\mu_0 = m_Z$, namely

$$\alpha_s(m_Z) = 0.1192 \pm 0.0028;$$

$$\sin^2 \Theta_W(m_Z) = 0.23117 \pm 0.00016$$

$$\alpha^{-1}(m_Z) = 127.938 \pm 0.027$$

Then due to RG equations these parameters can be determined at the higher and experimentally tested scale $\mu_0 = 2m_t$. With the experimental data for couplings at this scale we can combine experimentally known parameters and rewrite eq.(1) in the following form:

$$D(\alpha)_{2m_t} + \frac{1}{2\pi}\{\frac{8}{5}\ln\frac{m_D}{m_{\tilde{h}}} + \frac{4}{5}\ln\frac{m_{\tilde{D}}}{m_H} + 4\ln\frac{m_{\tilde{G}}}{m_{\tilde{\chi}}} + \frac{1}{5}\ln\frac{m_{\tilde{q}_1}\cdot m_{\tilde{q}_2}\cdot m_{\tilde{q}_3}}{m_{\tilde{l}_1}\cdot m_{\tilde{l}_2}\cdot m_{\tilde{l}_3}}\} = 0 \tag{2}$$

Here

$$D(\alpha)_{2m_t} = (\alpha_1^{-1} - 3\cdot\alpha_2^{-1} + 2\cdot\alpha_3^{-1})_{2m_t}$$

and all m_i are characteristic scales for different dynamical families. Analogously it is easy to find equation for the scale M_{GUT}:

$$G(\alpha)_{2m_t} + \frac{1}{2\pi}\{-\frac{2}{3}\ln\frac{m_D}{m_{\tilde{h}}} - \frac{1}{3}\ln\frac{m_{\tilde{D}}}{m_H} - 2\ln\frac{m_{\tilde{G}}}{m_{\tilde{\chi}}} - \frac{1}{6}\ln\frac{m_{\tilde{q}_1}\cdot m_{\tilde{q}_2}\cdot m_{\tilde{q}_3}}{m_{\tilde{l}_1}\cdot m_{\tilde{l}_2}\cdot m_{\tilde{l}_3}} - \frac{2}{3}\ln\frac{m_{\tilde{\chi}}}{2m_t} - 3\ln\frac{M_{GUT}}{2m_t}\} = 0 \tag{3}$$

Here arises the combination which is fixed experimentally:

$$G(\alpha)_{2m_t} = (\alpha_2^{-1} - \alpha_3^{-1})_{2m_t}$$

It is important that the expressions for $D(\alpha)_{2m_t}$ and $D(\alpha)_{2m_t}$ contain all information about SM interactions and are measured at available energies.

From these formulas it is easy to get known results for the MSSM [5] with the specific choice of scales:

$$m_D \approx m_{\tilde{D}} \approx M_{GUT},$$

$$m_{\tilde{h}} \approx m_H \approx m_{\tilde{G}} \approx m_{\tilde{\chi}} \approx m_{\tilde{q}_i} \approx m_{\tilde{l}_i} \approx M_{SUSY}.$$

The main feature of this hypothesis is that chromodynamics degrees of freedom — D and $\tilde{D}$ — do not contribute to coupling running because they have masses near M_{GUT} and electro-weak states — H and $\tilde{h}$ — remain at sufficiently low scale M_{SUSY}. From the above equations immediately follows:

$$\ln\frac{M_{SUSY}}{2m_t} = \frac{2\pi}{11}(5\alpha_1^{-1} - 12\alpha_2^{-1} + 7\alpha_3^{-1})_{2m_t}, \tag{4}$$

$$\ln\frac{M_{GUT}}{2m_t} = \frac{\pi}{66}(5\alpha_1^{-1} + 21\alpha_2^{-1} - 26\alpha_3^{-1})_{2m_t}. \tag{5}$$

These results are well known formulas for MSSM with "desert" from SUSY scale near 1 TeV up to M_{GUT}. As it can be seen, the way to get MSSM from SUSY $SU(5)$ is to decouple singlet states $D, \tilde{D}$ from their partners in supermultiplets — Higgs and higgsino — and assign them very high scale near M_{GUT}. What is most important that there are no dynamical reasons for this decoupling, despite the avoiding of some additional fast proton decay channel in SUSY [11]. Thus, if there are no other reasons to forbid this channel, the set of scales cannot be determined unambiguously, and the MSSM variant is not unique. Thus in the SUSY $SU(5)$ framework there are only following criteria for the determination of the scale sequence:

1) all color states are heavier than electro-weak in average;

2) for the proton stability it is necessary that $M_{GUT} \geq 10^{15}$ GeV;

3) Higgs state should be comparatively light ($\sim M_{SUSY} \approx 1$ TeV) and, for the UV-stability and unitarity, be not far from the EW scale .

If these conditions are satisfied, from the RG equations (2) and (3) it is possible to find a lot of variants for SUSY $SU(5)$ spectra of energetic scales. In the way as it has been found the "naturalness" is keeping together with stability of the model ($M_{SUSY} \approx 1$ TeV) and $M_{GUT} \approx 10^{15}$ GeV. If we can avoid the extra channel for proton decay, then there are no dynamical reasons for the singlet quarks to be heavy as M_{GUT}, moreover the estimation is [12, 13, 14] $m_D \geq 0.5$ TeV, and its effects are comparable with contributions of superparticles in the region ~ 1 TeV and/or higher. In this case all singlet states are lower than M_{GUT}, though they are heavy enough.

Let us look at some examples and firstly fix only two global scales — color M_C and weak M_W — with the sequences $m_D \sim m_{\tilde{D}} \sim m_{\tilde{G}} \sim m_{\tilde{q}_i} \sim M_C$; $m_{\tilde{h}} \sim m_H \sim m_{\tilde{\chi}} \sim m_{\tilde{l}_i} \sim M_W$. Then from (2) and (3) we get the ratio $M_C/M_W \approx 1.2 \cdot 10^4$ and $M_{GUT} \approx 1.3 \cdot 10^{15}$ GeV.

In the other case we keep singlet quarks at "low" scale, i.e. $m_{\tilde{h}} \sim m_H \sim m_D \sim m_{\tilde{D}} \sim 1$ TeV and put other degrees of freedom again at two different scales — color and weak. For this choice from the above RG equations it can be found that $M_C/M_W \approx 1.0 \cdot 10^6$ and $M_{GUT} \approx 0.8 \cdot 10^{15}$ GeV.

Certainly each sequence of scales has specific set of experimental verifications, in particular, if only two scales exist, the electro-weak objects will be seen at available energies in the nearest future only. Another variant with sufficiently light Higgs can be realized, if at the scale ~ 1 TeV there are $\tilde{h}, H, D$, and the remaining electro-weak, but color states "live" at higher scale. For this case are the following results: $M_C/m_H \approx 1.9 \cdot 10^5$, $M_{GUT} \approx 1.0 \cdot 10^{15}$ GeV. It is possible, in principle, to construct the whole "stairway" of scales from electro-weak scale ~ 1 TeV up to M_{GUT}, so in this case the "desert" is populated by different particles.

Thus the RG analysis of simplest SUSY extensions leads to conclusions:

1) the MSSM spectra of scales follows from SUSY $SU(5)$ via decoupling of singlet quarks, i.e. by destruction of corresponding $SU(5)$ multiplets;

2) Higgs scale is near SM electro-weak scale;

3) color states should be heavier than weak states;

4) GUT scale is at high value $\approx 10^{15}$ GeV;

5) the possibility to observe superpartners for quarks and leptons is significant only at energies $\sim 10^4$ TeV.

Let us now come back to the SM problems and remind (see Introduction) that most naturally they should be studied in the framework of superstring models and reductions of them.

3 Models caused by E_6 and their energetic scales

As it was noted earlier [7, 8, 10] (see also [4, 5]) there are schemes of E_6 reduction with the rank conserving. In the minimal SUSY E_6 all known particles are in three chiral 27-plets and gauge 78-plet of the group. Corresponding dynamical E_6 families are:

— three generations of standard fermions and gauge bosons with their superpartners;

— three generations of new leptons that are L and R doublets $\chi_{L,R}$ and heavy neutrino ν_R, N_R with their superpartners (Higgses);

— new gauge bosons with their superpartners;

— three generations of singlet quarks $D_{L,R}$ and their superpartners.

Usual Higgs mechanism is absent in this case, because there is no need to introduce scalar fields, so this high-level symmetry can be reduced to the SM symmetry only due to existence of topological defects in the 6-dimension Calabi-Yau space [5]. Several groups resulting from E_6 reduction with conserving the rank $r = 6$ are known, in particular [8, 10]:

$$E_6 \to U''(1) \times U'(1) \times U(1) \times SU_L(2) \times SU_c(3),$$

or

$$E_6 \to SU_c(3) \times SU_L(3) \times SU_R(3).$$

Here we will consider the former type of reduction only.

For this case, as it was noted earlier, there is no need to introduce extra scalar fields, all needed degrees of freedom are in 27-plets from the beginning. Due to their presence two phase transitions take place at two scales, and it is important that all particles in 27-plets have zero masses above the top scale of the theory. Thus there are two neutral Z'' and Z' bosons corresponding to two intermediate scales of symmetry breaking Λ'' and Λ'. Perhaps the Z' boson can be useful for the electro-weak data fit. For some of new physical states generation of masses occurs at Λ'' scale, at the lower scale Λ' the state of ν_R acquires mass, and at the same energies mixing of standard and new fermions takes place. Standard fermions acquire masses at the SM scale, as usually. If we suppose for the Yukawa constants that correspond to new fermions that the hierarchy is the same as it is in the standard Yukawa sector, then we get $m_{\tilde{\chi}} \sim m_D \ll$ masses of other new objects. Now because of the symmetry of the model it is impossible to shift one of the multiplet component — singlet quarks $D_{L,R}$ — to the GUT level as in the SUSY $SU(5)$. It is significant that for this case there is no additional fast proton decay channel due to specific symmetry of the model.

In this situation we get from (1) RG equations for the E_6 theory that have invariant form identical to eq. (2) and (3):

$$D(\alpha)_{2m_t} + \frac{1}{2\pi}\{\frac{8}{5}\ln\frac{m_{D_1}\cdot mD_2\cdot mD_3}{m_{\tilde{h}_1}\cdot m_{\tilde{h}_2}\cdot m_{\tilde{h}_3}} + \frac{4}{5}\ln\frac{m_{\tilde{D}_1}\cdot m_{\tilde{D}_2}\cdot m_{\tilde{D}_3}}{m_{H_1}\cdot m_{H_2}\cdot m_{H_3}} + 4\ln\frac{m_{\tilde{G}}}{m_{\tilde{\chi}}} + \frac{1}{5}\ln\frac{m_{\tilde{q}_1}\cdot m_{\tilde{q}_2}\cdot m_{\tilde{q}_3}}{m_{\tilde{l}_1}\cdot m_{\tilde{l}_2}\cdot m_{\tilde{l}_3}}\} = 0, \quad (6)$$

$$G(\alpha)_{2m_t} + \frac{1}{\pi}\{\frac{2}{15}\ln\frac{m_{D_1}\cdot mD_2\cdot mD_3}{m_{\tilde{h}_1}\cdot m_{\tilde{h}_2}\cdot m_{\tilde{h}_3}} + \frac{1}{15}\ln\frac{m_{\tilde{D}_1}\cdot m_{\tilde{D}_2}\cdot m_{\tilde{D}_3}}{m_{H_1}\cdot m_{H_2}\cdot m_{H_3}} - \frac{2}{3}\ln\frac{m_{\tilde{G}}}{2m_t} -$$

$$\frac{1}{15}\ln\frac{m_{\tilde{q}_1}\cdot m_{\tilde{q}_2}\cdot m_{\tilde{q}_3}}{m_{\tilde{l}_1}\cdot m_{\tilde{l}_2}\cdot m_{\tilde{l}_3}} - 3\ln\frac{M_{GUT}}{2m_t}\} = 0. \quad (7)$$

Since now due to symmetry it is forbidden to consider $m_D \sim m_{\tilde{D}} \sim M_{GUT}$, the choice of some sufficiently low scale for these states is possible. For example, if the only superpartner $m_{\tilde{D}} \sim M_{GUT}$, $m_{\tilde{G}} \sim m_H \sim m_{SUSY}$ and the ratio $m_{D_i}/m_{\tilde{h}_i} \sim m_{\tilde{q}_i}/m_{\tilde{l}_i} \sim m_{\tilde{G}}/m_{\tilde{\chi}} \sim 1$, then we have from (6) and (7):

$$M_{SUSY} \approx 0.7\cdot 10^4 GeV,\ M_{GUT} \approx 5\cdot 10^{15} GeV.$$

If we suppose existence of two global scales — M_{color} and M_{weak} — with the condition $\frac{m_{D_i}}{m_{\tilde{h}_i}} \sim 1$ so these scales can be sufficiently low and for other states

$$\frac{m_{\tilde{D}_i}}{m_{H_i}} \sim \frac{m_{\tilde{G}}}{m_{\tilde{\chi}}} \sim \frac{m_{\tilde{q}_i}}{m_{\tilde{l}_i}} \sim \frac{M_{color}}{M_{weak}},$$

we get the value $\frac{M_{color}}{M_{weak}} \approx 0.6\cdot 10^4$ GeV. For the case $M_{weak} \sim 1$ TeV we find for GUT scale the nearly usual value $M_{GUT} \approx 2\cdot 10^{15}$ GeV.

It is interesting to consider a variant with only two global scales for all states. In this case from RG equations it follows:

$$M_{color}/M_{weak} \approx 260, M_{GUT} \approx 3.3\cdot 10^{15} GeV.$$

If we take into account known measurement errors for the set of initial parameters $\sin\Theta_W, \alpha_i(m_Z), m_Z, m_t$ [1] the conclusion is that this analysis does not change the scale estimation drastically. Namely, now we have the result

$$M_{color}/M_{weak} \approx 258^{+79}_{-61}, M_{GUT} \approx (3.25 \pm 0.37)\cdot 10^{15} GeV$$

In principle, as it has been shown, [1], the conclusion is that this analysis does not change the scale estimation drastically. Namely, now we have the result

$$M_{color}/M_{weak} \approx 258^{+79}_{-61}, M_{GUT} \approx (3.25 \pm 0.37)\cdot$$

In principle, as it has been shown, [1], the conclusion is that this analysis does not change the scale estimation drastically. Namely, now we have the result

$$M_{color}/M_{weak} \approx 258^{+79}_{-61}, M_{GUT} \approx (3.25 \pm 0.37)\cdot$$

In principle, as it has been shown, a variety of different energy scales can be found from one-loop RG equations. So there is a question: does energy "desert" really exist above the scale ~ 1 TeV and up to M_{GUT}? Unfortunately we do not know the answer neither for this question, nor for the more important one: are there some dynamical principles that determine a "stairway" of energy scales? Of course, the different sequences of scales can be distinguished one from another experimentally, but specific SUSY scenarios have different sets of states near 1 TeV, i.e.in the LHC region. Thus, for various possible spectra of states, different experimental strategies should be used. Moreover there is necessity to account for competition of effects from different channels [15]. The above RG analysis leads to important conclusion that color degrees of freedom should be heavier than the weak ones. So at the LHC scale, it is possible that there are no chances to see superparticles, except for superleptons and heavy singlet quarks. Of course, there are some schemes of energy spectra with sufficiently low (~ 1 TeV) superparticles that compensated by shifting of $\tilde{D}$ states up to GUT scale.

4 Conclusions

Here we list the main features of our one - loop RG results. It is interesting that we get nearly the same systems of equations for ratios of dynamical scales in the SUSY $SU(5)$ and E_6 models. The systems contain as initial parameters some combinations of running couplings that are fixed experimentally. So there is a link between low - energy behavior of couplings and distribution of scales for dynamical families in the model. The value of M_{GUT} is determined from these equations unambiguously, if the set of scales is fixed in some way.

From the RG equations for SUSY $SU(5)$ it is easy to get known spectra of scales for the MSSM: it is realized by maximal shifting of singlet quark states to M_{GUT}. But equations can give some other distributions of scales and, in principle, it is possible to construct the "staircase" of scales. So the "desert" above 1 TeV can be populated by heavy states, sparticles, for example. In the case it is possible that at LHC we will not observe any SYSY signals, or these signals will not coincide with known predictions.

From our analysis it follows that the condition of "naturalness" is conserved. The consistency of equations takes place with the condition $M_{color} > M_{weak}$ only. For all cases the value for M_{GUT} corresponds to proton stability.

More general consideration for the E_6 model with the rank conserving reduction leads to analogous equations for the scales. In this case, because of internal symmetry of the model, the fast proton decay mode is absent and nonstandard states can exist at some sufficiently low energetic scales.

Due to condition $M_{color} > M_{weak}$, signals of SUSY particles can be found at very high energies, so effects of nonstandard fermions from E_6 multiplets can mimic them in the LHC region.

As a general assertion it is possible to say that experimentally different scenarios can be separated from each other by comparison of production and decay channels for singlet quarks and/or heavy exotic leptons.

Unfortunately we do not know an answer for very important question: what is the mechanism for distribution of scales? It seems that the answer should be concerned with the nonperturbative origin of scales from interaction with physical vacuum. Then two - loop RG analysis can give only some small corrections to our estimations.

References

[1] D.E. Groom e.a. (Particle Data Group), Eur.J.Phys. C15 (2000) 1

[2] V. Beylin, G. Vereshkov, V. Kuksa, Elem.Part. and Atom.Nucl. v.32, (2001) N5

[3] M.A. Shifman, A.I. Vainshtein, V.I. Zakharov, Nucl.Phys. B147 (1979) 385

[4] P. West, Introduction to Supersymmetry and Supergravity (World Scientific Press, 1986)

[5] D.I. Kazakov, Usp.Fiz.Nauk v.150 (1986) N4

[6] B.M. Barbashov, V.V. Nesterenko, Usp.Fiz.Nauk v.150 (1986) N4

[7] P. Candelas, C.T. Horowitz, A. Strominger, E. Witten, Nucl.Phys. B258 (1985) 258

[8] E. Witten, Nucl.Phys. B258 (1985) 75

[9] M.B. Green, in: *Proceedings of HEP Conference*, Bari, Italy, 1985, p.28

[10] E. Witten, Nucl.Phys. B188 (1981) 513

[11] P. Nath, R. Arnowitt, Phys.Rev. D38 (1988) 1479

[12] V. Barger, M.S. Berger, R.J.N. Phillips, Phys.Rev. D52 (1995) 1663

[13] V. Beylin, G. Vereshkov, V. Kuksa, Yad.Phys. v.56 (1993) 186; v.58 (1995) 931

[14] W.-S. Choong, D. Silverman, Phys.Rev. D49 (1994) 2322

[15] V. Beylin, G. Vereshkov, V. Kuksa, in: *Proceedings of this Workshop on QFTHEP*, Moscow, 2001