$d = 5$ Operators in SUSY GUT: Fermion Masses Versus Proton Decay

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Abstract

In the minimal SU(5) SUSY GUT $d = 5$ operators lead to $p \to K^+\nu$ decay with the proton life time of the order of 10^{28} years for the natural choice of the parameters of the theory. This value is in strong contradiction with experimental bound $\tau_{p\to K\nu} > 10^{32}$ years. $d = 5$ operators are induced by colored Higgsino exchanges and are closely (through SU(5) and super symmetry) related to another wrong prediction of SU(5) SUSY GUT: $m_d/m_s = m_e/m_\mu$. We demonstrate how in the model where reasonable pattern of quark and lepton masses and CKM mixing angles are obtained proton decay can be suppressed and proton life time can be close to the present experimental bound.

1 Introduction

As everyone is aware of the most attractive candidate for the physics beyond the Standard Model is low-energy supersymmetry (see reviews [1]). It helps in solving hierarchy problem – so, GUT's get firm theoretical foundation. Experimental signal in favor of SUSY GUT comes from the numerical value of electroweak mixing angle, $\sin^2\theta^{exp} \approx 0.23$, which nicely coincides with SUSY GUT value, while contradicts non-SUSY GUT prediction $\sin^2\theta \approx 0.21$ [2]. Another manifestation of this phenomena is prediction of the $\alpha_s(M_Z)$ value which nicely coincides with LEP and other low-energy measurements.

One of the most spectacular prediction of Grand Unification is proton decay. In nonsupersymmetric theories proton decay through $d = 6$ operators mostly via $p \to e^+\pi^0$ channel. Modern experimental bound on this particular mode is $\tau_{p\to e^+\pi^0} \geq 10^{32}$ years which strongly contradicts prediction of the SU(5) GUT: $\tau_{p\to e^+\pi^0} = 10^{28\pm 2}$ years [3]. In supersymmetric GUT's operators with $d = 6$ are also generated. But since in SUSY GUT's unification scale is approximately 30 times larger than in non-SUSY GUT's, proton life time due to operators with $d = 6$ is of the order of 10^{34} years [1] which is beyond discovery possibilities because of background problems.

In supersymmetric models the $d = 4$ trilinear B and L violating couplings can be introduced. They mediate fast decay of proton. That is why one should impose on the theory condition of absence of such operators.

However, the $d = 5$ operators are induced in SUSY GUTs by exchange of the color-triplet Higgsinos, which are partners of the Higgs doublets in the GUT multiplets [4].

In the second section of this paper old result [5] for $\tau_{p\to K^+\nu}$ in SU(5) SUSY GUT will be reanalyzed. Feynman diagrams which induce this decay are shown on Fig. 1. This refreshment is necessary since at the time when [5] was written on the one hand lower experimental bound on $\tau_{p\to K^+\nu}$ was two orders of magnitude weaker than now, on the other hand, neither m_{top} was known nor Kobayashi-Maskawa mixing angles were measured with modern accuracy. Using these updated numbers together with old (but still valid) value of decay matrix element from [5] we get our central statement: proton decays too fast and we cannot naturally be within experimental bound [6]: $\tau_{p\to K^+\nu} > 10^{32}$ years. In this way we come to the following conclusion: minimal supersymmetric SU(5) GUT should be modified. In other words, some mechanism for suppression of the nucleon decay amplitude is necessary and we are not the only who shared this point of view [7].

In SO(10) theory suppression of the proton decay can occur for the following two reasons:

1) The scalar sector is arranged in such a way, that the nucleon decay parameter – $(M_T^{-1})_{11}$ vanish or is strongly suppressed [8]. SO(10) model in which the proton decay is strongly suppressed and in which gauge and fermion mass hierarchy was explained naturally was suggested in [9].

2) Another possibility of stabilizing the proton by implementing the 45-plet with VEV towards T_R direction in the Yukawa sector was suggested in

refs [10] [1] and [11].

Our approach here is different. We study $SU(5)$ SUSY GUT where unsatisfactory relations of minimal theory $m_\mu = m_s$ and $m_e = m_d$ at GUT scale are avoided.

These unsatisfactory predictions come from the same Higgs-matter multiplets couplings which generate $d = 5$ operators. Having in mind valuable way to solve the mass degeneracy problem we will work on $d = 5$ operator generated proton decay in this scheme. One can see that what is done in the present paper for the suppression of the nucleon decay in the framework of $SU(5)$ theory is analogous to what was proposed for $SO(10)$ SUSY GUT in [10] and [11]. It is natural to assume, that the renormalizable couplings with Higgs multiplets has only the third generation, while the lighter generations get masses through higher order terms, by the mixing with there nearest heavy neighbours [13]; we suppose that this higher order terms for up quarks are antisymmetric. Since qqT coupling is symmetric in the generation indices it vanishes for the light generations and exists only for the third family. This leads to the strong suppression of the nucleon decay.

The paper is organized as follows: In part 2 we present the $d = 5$ operators for general $SU(5)$ theory. Part 3 deals with proton decay in minimal SUSY SU(5). Part 4 contains the solution of $m_l = m_d$ problem in our extended $SU(5)$ SUSY GUTs. In part 5 we consider proton decay in our model and part 6 contains discussions and conclusions.

2 $d = 5$ Operators

Fermion sector of the SU(5) SUSY GUT consists of the one pair of fermion supermultiplets $\bar{5} + 10$ per generation:

$$\bar{5}_\alpha = (d^c, \quad l)_\alpha, \qquad 10 = (u^c, \quad q, \quad e^c)_\alpha \ , \tag{1}$$

where $\alpha = 1, 2, 3$ is a family index.

The Higgs sector contains the following chiral supermultiplets: $\Sigma \sim 24$ in adjoint representation of SU(5) and 5 and $\bar{5}$-plets H, $\bar{H}$:

$$H = (T, \quad H_u), \qquad \bar{H} = (\bar{T}, \quad H_d) \ . \tag{2}$$

[1]The analyses of the nucleon decay in this model was presented in [12].

The SU(5) invariant Yukawa couplings which generate masses of the up and down quarks and charged leptons are respectively:

$$10 \cdot \hat{\Gamma}_u \cdot 10H, \qquad 10 \cdot \hat{\Gamma}_d \cdot \bar{5}\bar{H}, \tag{3}$$

where $\hat{\Gamma}_u$ and $\hat{\Gamma}_d$ are Yukawa coupling constants (family and SU(5) indices are suppressed). Decomposition of these couplings in general have the form:

$$\Gamma^u 10 \cdot 10 \cdot H \to q\hat{Y}_u u^c H_u + q\hat{A}qT + u^c\hat{B}e^cT \ , \tag{4}$$

$$\Gamma^d 10 \cdot \bar{5} \cdot \bar{H} \to q\hat{Y}_d d^c H_d + q\hat{C}l\bar{T} + u^c\hat{D}d^c\bar{T} + e^c\hat{Y}_e l H_d \ . \tag{5}$$

After integrating out the colour Higgses T, $\bar{T}$ with masses of the order of M_{GUT} we obtain the following $d=5$ operators :

$$O_L = \frac{1}{M_{GUT}}(q\hat{A}q)(q\hat{C}l) \ , \tag{6}$$

$$O_R = \frac{1}{M_{GUT}}(u^c\hat{B}e^c)(u^c\hat{D}d^c) \ . \tag{7}$$

In general $\Gamma_{u,d}$ (see (3)) can be some functions of Σ/M, where Σ breaks SU(5) down to the $G_{123} \equiv U(1)_Y \times SU(2)_W \times SU(3)_C$ group at the scale $M_{GUT} \simeq 10^{16}$ GeV. M is some fundamental scale, $M \gg M_{GUT}$.

After diagonalization of the Yukawa matrices by biunitary transformations:

$$L_u^+\hat{Y}_u R_u = \hat{Y}_u^{Diag}, \qquad L_d^+\hat{Y}_d R_d = \hat{Y}_d^{Diag}, \qquad R_e^+\hat{Y}_e L_e = \hat{Y}_e^{Diag} \tag{8}$$

and by proper redefinition of the quark and lepton fields all operators can be rewritten in the mass eigenstate basis, where the interaction of the quark-lepton superfields with colour-triplets have the form:

$$q\hat{A}qT \to q_u L_u^+ \hat{A} L_d^* q_d T \ , \tag{9}$$

$$u^c\hat{B}e^cT \to u^c R_u^T \hat{B} R_e e^c T \ , \tag{10}$$

$$q\hat{C}l\bar{T} \to q_u L_u^+ \hat{C} L_e l_e \bar{T} - q_d L_d^+ \hat{C} L_e l_\nu \bar{T} \ , \tag{11}$$

$$u^c\hat{D}d^c\bar{T} \to u^c R_u^T \hat{D} R_d d^c \bar{T} \ ; \tag{12}$$

in this basis the current-gauge superfield interactions have the form:

$$g_2 q_u^+ \hat{V} q_d W^{(+)} + g_2 l_\nu^+ l_e W^{(+)} \tag{13}$$

where $\hat{V}$ is the CKM matrix:

$$\hat{V} = L_u^T L_d^* \tag{14}$$

The O_L type $d=5$ operators which induce proton decay with neutrino emission by exchange of wino lead to the following baryon number violating four-fermion interactions (we omit charge conjugation matrix in fermion braces throughout this paper):

$$\frac{1}{M_{\tilde{H}_3}} C^{(ud)(d\nu)}_{\delta\alpha\gamma\rho} \cdot (u_a^\delta d_b^\alpha)(d_c^\gamma \nu^\rho)\varepsilon^{abc} \tag{15}$$

where

$$C = C(I) + C(II) + C(III) + C(IV) \ , \tag{16}$$

$$C^{(ud)(d\nu)}_{\delta\alpha\gamma\rho}(I) = -g_2^2 (L_d^+ \hat{C} L_e)_{\gamma\rho} (L_u^+ \hat{A} L_d^*)_{\beta\sigma} V_{\beta\alpha} (V^+)_{\sigma\delta} I(\tilde{u^\beta}, \tilde{d^\sigma}) \ , \tag{17}$$

$$C^{(ud)(d\nu)}_{\delta\alpha\gamma\rho}(II) = -g_2^2 (L_d^+ \hat{A} L_u^*)_{\gamma\beta} V_{\beta\alpha} (L_e^T \hat{C}^T L_d^*)_{\rho\sigma} (V^+)_{\sigma\delta} I(\tilde{u^\beta}, \tilde{d^\sigma}) \ , \tag{18}$$

$$C^{(ud)(d\nu)}_{\delta\alpha\gamma\rho}(III) = g_2^2 (L_u^+ \hat{A} L_d^*)_{\delta\alpha} (L_u^+ \hat{C} L_e)_{\beta\rho} V_{\beta\gamma} I(\tilde{u}^\beta, \tilde{e}^\rho) \ , \tag{19}$$

$$C^{(ud)(d\nu)}_{\delta\alpha\gamma\rho}(IV) = -g_2^2 (L_d^+ \hat{A} L_u^*)_{\alpha\beta} V_{\beta\gamma} (L_u^+ \hat{C} L_e)_{\delta\rho} I(\tilde{u^\beta}, \tilde{e^\rho}) \ , \tag{20}$$

while the operators with charged leptons are:

$$\frac{1}{M_{\tilde{H}_3}} C^{(ud)(ue)}_{\alpha\beta\delta\rho} \cdot (u_a^\alpha d_b^\beta)(u_c^\delta e^\rho)\varepsilon^{abc} \tag{21}$$

where

$$C = C(I) + C(II) + C(III) + C(IV) \ , \tag{22}$$

$$C^{(ud)(ue)}_{\alpha\beta\delta\rho}(I) = -g_2^2 (L_u^+ \hat{A} L_d^*)_{\alpha\beta} (L_d^+ \hat{C} L_e)_{\sigma\rho} \quad (V^+)_{\sigma\delta} I(\tilde{d^\sigma}, \tilde{\nu^\rho}) \ , \tag{23}$$

$$C^{(ud)(ue)}_{\alpha\beta\delta\rho}(II) = g_2^2 (L_u^+ \hat{A} L_d^*)_{\alpha\gamma} (V^+)_{\gamma\delta} (L_d^+ \hat{C} L_e)_{\beta\rho} I(\tilde{d^\gamma}, \tilde{\nu^\rho}) \ , \tag{24}$$

$$C^{(ud)(ue)}_{\alpha\beta\delta\rho}(III) = g_2^2 (L_u^+ \hat{C} L_e)_{\delta\rho} (L_u^+ \hat{A} L_d^*)_{\gamma\sigma} V_{\gamma\beta} (V^+)_{\sigma\alpha} I(\tilde{d^\sigma}, \tilde{u^\gamma}) \ , \tag{25}$$

$$C^{(ud)(ue)}_{\alpha\beta\delta\rho}(IV) = g_2^2 (L_u^+ \hat{A} L_d^*)_{\delta\gamma} (V^+)_{\gamma\alpha} (L_e^T \hat{C}^T L_u^*)_{\rho\omega} V_{\omega\beta} I(\tilde{d^\gamma}, \tilde{u^\omega}) \tag{26}$$

(α, β,... and $a, b, ...$ are the family and colour indices respectively). $C(I)$ and $C(III)$ correspond to the vertex diagrams (see Figs. 2a,c,e,g) while $C(II)$ and $C(IV)$ to the box diagrams(see Figs. 2b,d,f,h). In (19)-(26) I denotes the result of the integral over the loop and is given by the following formula [19]:

$$I(\tilde{u}, \tilde{d}) = \frac{1}{16\pi^2} \frac{m_{\tilde{W}}}{m_{\tilde{u}}^2 - m_{\tilde{d}}^2} \left(\frac{m_{\tilde{u}}^2}{m_{\tilde{u}}^2 - m_{\tilde{W}}^2} \ln \frac{m_{\tilde{u}}^2}{m_{\tilde{W}}^2} - \frac{m_{\tilde{d}}^2}{m_{\tilde{d}}^2 - m_{\tilde{W}}^2} \ln \frac{m_{\tilde{d}}^2}{m_{\tilde{W}}^2} \right) \ , \tag{27}$$

and analogously for $I(\tilde{d}, \tilde{\nu})$ and $I(\tilde{u}, \tilde{e})$.

For degenerate squark masses from (27) we get:

$$I(\tilde{u}, \tilde{d}) \to I(m_{\tilde{q}}, x_w) = \frac{1}{16\pi^2} \frac{\sqrt{x_w}}{m_{\tilde{q}}} \frac{1}{(1 - x_w)^2} (x_w \ln x_w - x_w + 1) \ , \tag{28}$$

where

$$x_w = \left(\frac{m_{\tilde{W}}}{m_{\tilde{q}}} \right)^2 \ . \tag{29}$$

The function $I(m_{\tilde{q}}, x_w)$ has the following behaviour:

$$16\pi^2 m_{\tilde{q}} I(m_{\tilde{q}}, x_w) = \begin{cases} \frac{\ln x_w}{\sqrt{x_w}} & \text{if } x_w \gg 1 \\ 0.5 & \text{if } x_w = 1 \\ \sqrt{x_w} & \text{if } x_w \ll 1 \end{cases} \tag{30}$$

In order to estimate stop contribution the following relations will be used:

$$m_{\tilde{t}}^2 = m_{\tilde{q}}^2 + m_t^2 \ , \tag{31}$$

$$I(\tilde{t}, \tilde{d}) = \frac{1}{16\pi^2} \frac{m_{\tilde{W}}}{m_t^2} \frac{m_t^2 x_w \ln x_w + (m_{\tilde{q}}^2 + m_t^2)(1 - x_w) \ln(1 + m_t^2/m_{\tilde{q}}^2)}{m_t^2 (1 - x_w) + (1 - x_w)^2 m_{\tilde{q}}^2} \ . \tag{32}$$

3 Proton decay in minimal SUSY SU(5)

In minimal SU(5) Γ_u and Γ_d are SU(5) singlets and the following relation between the Yukawa matrices occurs at the GUT scale:

$$\hat{Y}_u = \hat{A} = \hat{B} \; , \qquad \hat{Y}_d = \hat{Y}_e = \hat{C} = \hat{D} \; . \tag{33}$$

In addition in the minimal SU(5) theory $\hat{\Gamma}_u^T = \hat{\Gamma}_u$ which leads to equality of matrices which are used to transform u and u^c to mass eigenstate basis. Therefore in the mass eigenstate basis these couplings have the form:

$$\Gamma^u 10 \cdot 10 \cdot H \to q \hat{Y}_u^{Diag} u^c H_u + q_u \hat{Y}_u^{Diag} V q_d T + u^c \hat{Y}_u^{Diag} V^* e^c T \; , \tag{34}$$

$$\begin{aligned} \Gamma^d 10 \cdot \bar{5} \cdot \bar{H} \to & \; q \hat{Y}_d^{Diag} d^c H_d + e^c \hat{Y}_e^{Diag} l H_d + q_u V^* \hat{Y}_d^{Diag} l_e \bar{T} - \\ & q_d \hat{Y}_d^{Diag} l_\nu \bar{T} + u^c V^* \hat{Y}_d^{Diag} d^c \bar{T} \; , \end{aligned} \tag{35}$$

where V is the CKM matrix.

Taking into account the renormalization effects between the GUT scale and the SUSY scale the equalities (33) are violated. Using the (33) as a boundary conditions, at the SUSY breaking scale the $\hat{A} \otimes \hat{C}$ and the $\hat{B} \otimes \hat{D}$ from (6) can be expressed by the $Y_u \otimes Y_d$ product:

$$\hat{A} \otimes \hat{C} = (A_S)_L \, (\hat{Y}_u \otimes \hat{Y}_d) \; , \tag{36}$$

$$\hat{B} \otimes \hat{D} = (A_S)_R \, (\hat{Y}_u \otimes \hat{Y}_d) \; . \tag{37}$$

The A_S coefficients describe the renormalization effect between the GUT and SUSY breaking scales. The numerical effect of A_S factor will be discussed in what follows.

Calculation of the amplitude of proton decay consists of two steps: calculation of 1-loop Feynman diagram(s) where transition between sparticles and particles occur and calculation of matrix element of the corresponding four-fermion operator between proton and $K\nu$ system. Quarks and leptons of the second and/or the third generations give the main contribution. As these particles (except neutrinos and s-quark) do not participate in proton decay, their scalar superpartners go into the loop and are transformed into light species through wino exchange. Diagrams which describe the decay $p \to K\nu_\mu$ are shown on Fig. 1. Sum of the amplitudes which are given by diagrams shown on Fig. 1b and Fig. 1c equals zero, and we are left with four diagrams shown on Fig. 1a.

As it usually occurs in SUSY models, vertices on the diagrams shown on Fig. 1 are known – they are the same as in nonsupersymmetric SU(5). Less is known about propagators – masses of squarks and wino. Let us remind, that two Weyl higgsinos from two Higgs doublets with unit charge mixes with two Weyl winos and two massive Dirac particles are formed. Mixing matrix contain four parameters $\mu, M_{\tilde{W}}, g_2 v_1/2, g_2 v_2/2$ which are constrained by one equation:

$$(\frac{g_2 v_1}{2})^2 + (\frac{g_2 v_2}{2})^2 = M_W^2 \quad . \tag{38}$$

In SUSY GUT $m_{\tilde{W}} = \alpha_2/\alpha_3 m_{\tilde{g}}$, where $m_{\tilde{g}}$ is gluino mass. Since from Tevatron bounds gluino should weight several hundreds GeV at least, we have $m_{\tilde{W}} \gg g_2 v_1/2, g_2 v_2/2$ and instead of dealing with two mass eigenstates in box diagram we could take into account only $\tilde{W}$-bosino exchange.

Calculating diagrams of Fig. 1a we obtain

$$\begin{aligned} M &= 2 \cdot \frac{m_c m_s V_{cd} V_{us} (g_2)^2}{(v_1/\sqrt{2}) \cdot (v_2/\sqrt{2})} \frac{1}{M_{\tilde{H}_3}} I(\tilde{u}, \tilde{d}) A_S^l A_L \times \\ & [(\nu_L d_L^a)(u_L^b s_L^c) + (\nu_L s_L^a)(u_L^b d_L^c)]\varepsilon_{abc} \ , \end{aligned} \tag{39}$$

where for triplet higgsino-matter coupling constant we use $f = m_q V_{ik}/(v/\sqrt{2})$. W-bosino transform sparticles into particles with the constant g_2. Factors A take into account short (A_S) and long (A_L) distance renormalizations of decay amplitude. The index l of A_S^l refer to the contribution of the two light generation particles propagating inside the box diagram of Fig. 1a . Factor A_L is the long-range renormalization factor due to the QCD interaction between the SUSY breaking scale and 1 GeV scale [18]:

$$A_L = \left(\frac{\alpha_3(1\text{GeV})}{\alpha_3(m_c)}\right)^{-2/3} \left(\frac{\alpha_3(m_c)}{\alpha_3(m_b)}\right)^{-18/25} \left(\frac{\alpha_3(m_b)}{\alpha_3(m_Z)}\right)^{-18/23} \tag{40}$$

and for $\alpha_3(m_Z) = 0.120$ using α_3 running at two loops we get $A_L = 0.32$.

In (39) factor 2 comes from 2 diagrams, V_{ik} are the elements of Kobayashi-Maskawa matrix, v_1 and v_2 are Higgs fields vacuum expectation values and $M_{\tilde{H}_3}$ is mass of Higgs triplet, $M_{\tilde{H}_3} \approx M_{GUT} = 10^{16}$ GeV (let us remind that for minimal SUSY SU(5) Higgs triplets interactions with quarks and leptons which generate operator O_L are described by the Kobayashi-Maskawa matrix).

It is convenient to rewrite (39) introducing angle β, $\tan\beta = v_1/v_2$ and expressing $v_1^2 + v_2^2$ through G_F:

$$M = \frac{8\sqrt{2} G_F m_c m_s g_2^2 V_{cd} V_{us}}{M_{\tilde{H}_3} \sin(2\beta)} I(m_{\tilde{q}}, x_w) A_L A_S^l [(\nu_L d_L^a)(u_L^b s_L^c) + (\nu_L s_L^a)(u_L^b d_L^c)] \varepsilon_{abc} \, . \tag{41}$$

For the matrix element of operator (41) between hadronic states we use the result obtained in [5] :

$$\langle \nu K^+ | \varepsilon^{abc} [(\nu_L d_L^a)(u_L^b s_L^c) + (\nu_L s_L^a)(u_L^b d_L^c)] | p \rangle = \frac{\sqrt{2}\tilde{\beta} G}{(M_\Lambda + M_\Sigma)/2} (\nu P_L p) K \, , \tag{42}$$

where $P_L = \frac{1}{2}(1 + \gamma_5)$.

Finally, from (41) and (42) we get:

$$M_{p \to K\nu} = \frac{16 \cdot \tilde{\beta} G G_F m_c m_s g_2^2 V_{cd} V_{us}}{M_{\tilde{H}_3} \sin 2\beta [(M_\Lambda + M_\Sigma)/2]} I(m_{\tilde{q}}, x_w) A_L A_S^l (\nu P_L p) \equiv x (\nu P_L p) K \, . \tag{43}$$

Short distance renormalization factor A_S depends on the numerical value of $\tan\beta$ [19]. Making an attempt to suppress the proton decay amplitude we take the value of $\tan\beta$ which minimize the ratio $\frac{A_S^l}{\sin 2\beta}$; so we use $\sin\beta = 0.965$ ($\tan\beta = 3.68$), $A_S^l = 1.4$, $\frac{A_S^l}{\sin 2\beta} = 2.79$ (detailed calculations will be published in an extended paper).

Substituting numbers in (43) we get:

$$\Gamma = \frac{(m_p^2 - m_K^2)^2}{32\pi m_p^3} x^2 = \Bigg(\frac{m_c}{1.3 \text{ GeV}} \frac{m_s}{175 \text{ MeV}} \frac{10^{16}\text{GeV}}{M_{\tilde{H}_3}} \frac{\tilde{\beta}}{0.007\text{GeV}^3} \times$$

$$\frac{I(m_{\tilde{q}}, x_w)}{I(500\text{GeV}, 1)} \frac{A_L}{0.32} \frac{A_S^l}{1.4} \frac{0.51}{\sin 2\beta} \Bigg)^2 \frac{1}{4.5 \cdot 10^{27}\text{years}} \, . \tag{44}$$

Modern experimental bound is $\tau_{p \to K\nu} > 10^{32}$ years [6]. Variation of parameters could hardly help in enhancing proton lifetime that much. $\tilde{q}$ and $\tilde{W}$ with mass scale several TeV did not seem appealing, neither is $m_{\tilde{H}_3} \approx 10^{18}$ GeV (let us remind that SUSY GUT unification scale is $M_{GUT} =$

Table 1: The value of proton life time in Standard SUSY $SU(5)$ in units of $4.5 \cdot 10^{27}$ yeares. Allowed domain of $m_{\tilde{W}}$, $m_{\tilde{q}}$ values is in low left corner.

$m_{\tilde{W}}$ / $m_{\tilde{q}}$	100 GeV	200 GeV	500 GeV	1 TeV	5 TeV	10 TeV
100 GeV	0.04	0.03	0.04	0.07	0.54	1.48
200 GeV	0.31	0.16	0.13	0.17	0.84	2.14
500 GeV	7.7	2.6	1	0.78	1.8	4.0
1 TeV	$1.1 \cdot 10^2$	30.7	7.8	4	4.2	7.4
5 TeV	$6.3 \cdot 10^4$	$1.6 \cdot 10^4$	$2.7 \cdot 10^3$	$7.7 \cdot 10^2$	10^2	78
10 TeV	10^6	$2.5 \cdot 10^5$	$4.1 \cdot 10^4$	$1.1 \cdot 10^4$	$7.8 \cdot 10^2$	$4 \cdot 10^2$

10^{16} GeV and $M_{\tilde{H}_3} \approx \lambda/g \cdot M_{GUT}$, where g is gauge coupling at unification scale, while λ is a constant of Higgs multiplets selfinteraction).

The proton lifetime for the different values of squark and wino masses are presented in Table 1 . As we see the reasonable lifetime is obtained for $m_{\tilde{q}} = 5 - 10$ TeV and $m_{\tilde{W}}$ about 1 TeV or less (in this domain x_w is small and the function $m_{\tilde{q}} I(m_{\tilde{q}}, x_w)$ can be described by the asymptotic formula (30)). If one wants to have lighter quarkino, with mass less then, say 1 TeV, then proton decay should be somehow suppressed.

Before we will go to the main part of our paper let us estimate how much the contribution of the third generation particles in the proton decay amplitude can be. If instead of $\tilde{s}_L$ ($\tilde{\mu}_L$) on Fig. 1a we substitute $\tilde{b}_L$ ($\tilde{\tau}_L$), we will get the following extra factor in the amplitude (39):

$$\frac{A_S^h(\tilde{b})}{A_S^l} \frac{m_b}{m_s} \left| \frac{V_{ub}}{V_{us}} \right| = \frac{4.1 \div 4.5}{0.1 \div 0.3} \times \frac{0.002 \div 0.005}{0.22} = 0.1 \div 1 \ . \tag{45}$$

A_S^h is the short range renormalization factor for the heavy generations and $A_S^h(\tilde{b}) = A_S^l$.

Stop substituted instead of $\tilde{c}_L$ on the upper line of Fig. 1a lead to the following factor in the amplitude (39):

$$\frac{A_S^h(\tilde{t})}{A_S^l} \frac{I(\tilde{t}, \tilde{d})}{I(\tilde{u}, \tilde{d})} \frac{\eta_t m_t}{m_c} \left| \frac{V_{td} V_{ts}}{V_{cd}} \right| =$$

$$\frac{1.9}{1.4} \frac{6.1 \cdot 10^{-6}}{6.3 \cdot 10^{-6}} \frac{2.4 \cdot 180}{1 \div 1.6} \frac{(0.004 \div 0.014) \times (0.034 \div 0.046)}{0.22} = 0.3 \div 1.5 \ , \tag{46}$$

where we use $m_{\tilde{q}} = m_{\tilde{W}} = 500$ GeV. $A_S^h(\tilde{t}) = 1.9$.

Let us stress that amplitude (41) is defined at $\mu = 1$ GeV. Since t-quark mass is not renormalized from the virtuality which equals to its pole value $m_t = 180$ GeV to virtuality 1 GeV a compensation factor η_t should be introduced in A_L :

$$\eta_t = \frac{\bar{m}_t(1 \text{ GeV})}{m_t} = \left[\frac{\alpha_3(1 \text{ GeV})}{\alpha_3(m_t)} \right]^{\frac{4}{11 - \frac{2}{3} \cdot 5}} \tag{47}$$

for $\alpha_3(M_Z) = 0.120$ this factor equals 2.4.

¿From (45) and (46) we see, that for the maximum mixing between first and third generation allowed experimentally contribution of third generation particles into proton decay can compete with that of second generation. Amplitude with intermediate stop interfere with that with intermediate scalar charm quark and may partly cancel it; however compensation with 1% accuracy which is needed to satisfy experimental bound $\tau_{p\to\nu K} > 10^{32}$ years is unnatural.

4 Predictive ansatz for Yukawa couplings and suppression of proton decay

By focusing on the fermion mass pattern, it is natural to suggest that only the third, heaviest family acquires masses through ordinary renormalizable Yukawa couplings, while the mass terms of other families appear from higher order (may be Planck scale) operators, which can be generated by heavy particle exchange mechanism [20]:

$$W_Y^u = \frac{1}{4}C' \cdot 10 \cdot 10H + \frac{1}{4}\frac{B'}{M} \cdot 10 \cdot 10 \cdot \Sigma H + \frac{A'}{M^2} \cdot 10 \cdot 10 \cdot \Sigma^2 H \ , \tag{48}$$

$$W_Y^d = \sqrt{2}d \cdot 10 \cdot \bar{5}\bar{H} + \sqrt{2}\frac{b'}{M} \cdot 10 \cdot \bar{5} \cdot \Sigma \cdot \bar{H} + \sqrt{2}\frac{a'}{M^2} \cdot 10 \cdot \bar{5} \cdot \Sigma^2 \cdot \bar{H} \ , \tag{49}$$

where C', B',... are matrices in generation space.

In order to be closer to the realistic mass matrices let us suggest for them the following form:

$$C'_{\alpha\beta} \sim \delta_{3\alpha}\delta_{3\beta} \ , \quad B'_{\alpha\beta} \sim \delta_{3\alpha}\delta_{2\beta} + k_B\delta_{2\alpha}\delta_{3\beta} \ , \quad A'_{\alpha\beta} \sim \delta_{2\alpha}\delta_{1\beta} + k_A\delta_{1\alpha}\delta_{2\beta} \ ,$$
$$d_{\alpha\beta} \sim \delta_{3\alpha}\delta_{3\beta} \ , \quad b'_{\alpha\beta} \sim \delta_{2\alpha}\delta_{2\beta} \ , \quad a'_{\alpha\beta} \sim \delta_{2\alpha}\delta_{1\beta} + k_a\delta_{1\alpha}\delta_{2\beta} \ . \tag{50}$$

In (50) k are Clebsch factors. For W_Y^u we get:

$$10 \times 10 = \bar{5} + \overline{45} + \overline{50} \ , \tag{51}$$

while for W_Y^d we have:

$$10 \times \bar{5} = 5 + 45 \ . \tag{52}$$

For the bilinear Higgs fields product we have:

$$24 \times 5 = 5 + 45 + 70 \ , \tag{53}$$

so the ΣH could belong to 5 or 45 and in these cases B' is symmetric ($k_B = 1$) or antisymmetric ($k_B = -1$), respectively. However, because in $24 \times 24 \times 5$ several invariants of 5 and 45 plets and also 50-plet do occur, there exist many invariants and many possibilities for k_A and k_a's.

In what follows matrices A', B' will be taken antisymmetric ($k_A = k_B = -1$) and this will be crucial for the proton stability.

In other words we suppose that for some reason the composite operators ΣH and $\Sigma^2 H$ are participate in expression (48) only in representation 45 .

Insertion of Σ in higher order terms helps to avoid the degeneracy of the masses of down quarks and charged leptons. As it was assumed matrices B' and A' are antisymmetric, while a' is symmetric with respect to the family indices. (This can be attributed to some symmetry reasons). Then after substituting the VEVs of Σ, H and $\bar{H}$ Yukawa matrices for up and down quarks and leptons will have the forms:

$$\hat{Y}_u = \begin{pmatrix} 0 & A & 0 \\ -A & 0 & B \\ 0 & -B & C \end{pmatrix}, \qquad \hat{Y}_d = \begin{pmatrix} 0 & a_1 & 0 \\ a_1 & b_1 & 0 \\ 0 & 0 & d \end{pmatrix}, \qquad \hat{Y}_e = \begin{pmatrix} 0 & a_2 & 0 \\ a_2 & b_2 & 0 \\ 0 & 0 & d \end{pmatrix}. \tag{54}$$

Because according to our choice B' and A' matrices are antisymmetric in the family space while the qqT coupling is symmetric on the generation indices only 33 element of the matrix $\hat{A}$ is nonvanishing (as we will see this fact is crucial for proton decay):

$$\hat{A} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & C \end{pmatrix}, \quad \hat{B} = \begin{pmatrix} 0 & \tilde{A} & 0 \\ -\tilde{A} & 0 & \tilde{B} \\ 0 & -\tilde{B} & C \end{pmatrix}, \tag{55}$$

$$\hat{C} = \begin{pmatrix} 0 & \tilde{a}_1 & 0 \\ \tilde{a}_1 & \tilde{b}_1 & 0 \\ 0 & 0 & d \end{pmatrix}, \qquad \hat{D} = \begin{pmatrix} 0 & \tilde{a}_2 & 0 \\ \tilde{a}_2 & \tilde{b}_2 & 0 \\ 0 & 0 & d \end{pmatrix}. \tag{56}$$

The values of matrix elements of matrices (54), (55), (56) depend on the $SU(5)$ representations to which higher order Higgs terms in (48), (49) belong. In numerical estimates we will take $\tilde{a_1} = a_1$; concerning $\tilde{b_1}$ two possibilities will be considered (see later).

Structure of the matrices (54) resembles the ansatz proposed by Georgi and Jarlskog in an $SU(5)$ GUT [21]. Lately a number of authors [22, 24] have reexamined this texture in a supersymmetric context. From (54) it is easy to find, that

$$A \approx \sqrt{\lambda_u \lambda_c}\ , \quad B \approx \sqrt{\lambda_c \lambda_t}\ , \quad C \approx \lambda_t\ , \quad a_1 \approx \sqrt{\lambda_d \lambda_s}\ , \quad b_1 \approx \lambda_s\ ,$$

$$a_2 \approx \sqrt{\lambda_e \lambda_\mu}\ , \quad b_2 \approx \lambda_\mu\ , \quad d = \lambda_b = \lambda_\tau\ . \tag{57}$$

The Yukawa matrices are diagonalized by the transformations given in (8), where for $\hat{Y}$ from (54) we have:

$$L_u = L_u^{(23)} \cdot L_u^{(12)}\ , \qquad L_d = L_d^{(12)}\ , \qquad L_e = L_e^{(12)}\ , \tag{58}$$

where

$$L_u^{(12)} = \begin{pmatrix} \cos\theta_{12}^{L_u} & -\sin\theta_{12}^{L_u} & 0 \\ \sin\theta_{12}^{L_u} & \cos\theta_{12}^{L_u} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \qquad L_u^{(23)} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23}^{L_u} & -\sin\theta_{23}^{L_u} \\ 0 & \sin\theta_{23}^{L_u} & \cos\theta_{23}^{L_u} \end{pmatrix}, \tag{59}$$

$$L_d^{(12)} = \begin{pmatrix} \cos\theta_{12}^{L_d} & -\sin\theta_{12}^{L_d} & 0 \\ \sin\theta_{12}^{L_d} & \cos\theta_{12}^{L_d} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \qquad L_e^{(12)} = \begin{pmatrix} \cos\theta_{12}^{L_e} & -\sin\theta_{12}^{L_e} & 0 \\ \sin\theta_{12}^{L_e} & \cos\theta_{12}^{L_e} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \tag{60}$$

$$\sin\theta_{12}^{L_u} \simeq -\frac{AC}{B^2}\ , \quad \sin\theta_{23}^{L_u} \simeq -\frac{B}{C}\ , \quad \sin\theta_{12}^{L_d} \simeq -\frac{a_1}{b_1}\ , \quad \sin\theta_{12}^{L_e} \simeq -\frac{a_2}{b_2}\ . \tag{61}$$

Therefore at the GUT scale we have:

$$L_u = \begin{pmatrix} 1 & \frac{AC}{B^2} & 0 \\ -\frac{AC}{B^2} & 1 & \frac{B}{C} \\ \frac{A}{B} & -\frac{B}{C} & 1 \end{pmatrix}, \qquad L_d = \begin{pmatrix} 1 & \frac{a_1}{b_1} & 0 \\ -\frac{a_1}{b_1} & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}\ ,$$

$$L_e = \begin{pmatrix} 1 & \frac{a_2}{b_2} & 0 \\ -\frac{a_2}{b_2} & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}\ , \tag{62}$$

while for $R_{u,d,e}$ matrices we have:

$$R_u = \begin{pmatrix} 1 & \frac{AC}{B^2} & 0 \\ -\frac{AC}{B^2} & 1 & -\frac{B}{C} \\ -\frac{A}{B} & \frac{B}{C} & 1 \end{pmatrix} , \qquad R_d = \begin{pmatrix} -1 & \frac{a_1}{b_1} & 0 \\ \frac{a_1}{b_1} & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} ,$$

$$R_e = \begin{pmatrix} -1 & \frac{a_2}{b_2} & 0 \\ \frac{a_2}{b_2} & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} . \tag{63}$$

After diagonalization the Yukawa matrices have the form:

$$\hat{Y}_u^{Diag} = (\lambda_u,\ \lambda_c,\ \lambda_t) \ , \ \ \hat{Y}_d^{Diag} = (\lambda_d,\ \lambda_s,\ \lambda_b) \ , \ \ \hat{Y}_e^{Diag} = (\lambda_e,\ \lambda_\mu,\ \lambda_\tau) \ . \tag{64}$$

¿From (14), (57) and (62) one can find the CKM matrix elements:

$$V_{us} = \sqrt{\frac{\lambda_d}{\lambda_s}} - \sqrt{\frac{\lambda_u}{\lambda_c}} \ , \qquad V_{cb} = -\sqrt{\frac{\lambda_c}{\lambda_t}} \ , \quad V_{ub} = \sqrt{\frac{\lambda_u}{\lambda_t}} \ ,$$

$$V_{ts} = \sqrt{\frac{\lambda_c}{\lambda_t}} \ , \qquad V_{td} = -\sqrt{\frac{\lambda_c \lambda_d}{\lambda_t \lambda_s}} \ . \tag{65}$$

As we see on the GUT scale the value of the V_{cb} element is too large ($V_{cb}^{exp} = 0.036 \div 0.046$). It appears [22]-[24], that the desirable relations between masses and mixing angles are obtained on the electroweak breaking scale after taking into account the renormalization effects.

5 Proton decay in extended SUSY SU(5)

Let us estimate now the proton decay probability in our model. Let us start with $p \to K^+ \nu_\mu$ mode, which dominates in the minimal SU(5). This decay is described by the diagrams Fig. 2a-d.

¿From (62), (55) it is easy to see, that $(L_d^+ \hat{A} L_u^*)_{\alpha\beta}$ exactly vanish for $\alpha = 1, 2$. Therefore, the amplitudes (18), (19) and (20) do not lead to the proton decay as they produce b-quark in final state.

The amplitude described by eq. (17) is suppressed for another reason: as we see from (17) this amplitude do not vanish if $\sigma = 3$. However in the inner line of diagram Fig.2a $\tilde{u}$, $\tilde{c}$ and $\tilde{t}$ squarks run. Assuming for a moment that integral I in (17) is family independent, taking sum over β and using (14) we see that (17) is proportional to $(L_d^+ A L_d^*)_{\alpha 3}$ and in the external line still the b quark is produceed. In this way we see that d or s quarks which can participate in proton decay are not emitted. However the above argument is valid only if the equality $m_{\tilde{u}} = m_{\tilde{c}} = m_{\tilde{t}}$ holds; heaviness of the top quark breaks last equality, so $p \to K\nu$ decay through diagram Fig. 2a do occur. So, taking into account the shift of I function the nucleon decay will take place due to heavy stop exchange, but the suppression factor $\frac{\Delta I}{I}$ will appear, where ΔI is:

$$\Delta I = I(\tilde{t}, \tilde{b}) - I(\tilde{u}^\beta, \tilde{b}), \qquad \beta = 1, 2 \tag{66}$$

These arguments work for both $p \to K\nu$ and $p \to \pi\nu$ decays.

Introducing the parameter

$$F_w = \frac{8 g_2^2 G G_F A_S^h(\tilde{t}) A_L \tilde{\beta} I}{M_{\tilde{H}_3} \sin 2\beta} \ , \tag{67}$$

for the $p \to K\nu^\alpha$ decay widths [2] we get:

$$\Gamma(p \to K\nu_\mu) = \frac{(m_p^2 - m_K^2)^2}{32\pi m_p^3} F_w^2 \left(\frac{\Delta I}{I}\right)^2 \left(\frac{v_2}{\sqrt{2}}\right)^2 \bar{m}_t^2 |V_{ub}|^2 \times$$

$$\left| V_{ts}(C_{12} + C_{22} L_{d12}^+) \frac{2/3\alpha}{(M_\Lambda + M_\Sigma)/2} + V_{td} C_{22} \frac{1 - 2/3\alpha}{M_\Lambda} \right|^2 \ , \tag{68}$$

$$\Gamma(p \to K\nu_e) = \frac{(m_p^2 - m_K^2)^2}{32\pi m_p^3} F_w^2 \left(\frac{\Delta I}{I}\right)^2 \left(\frac{v_2}{\sqrt{2}}\right)^2 \bar{m}_t^2 |V_{ub}|^2 \times$$

$$\left| V_{ts}(C_{12}(L_e)_{21} + C_{21}(L_d^+)_{12} + C_{22}(L_d^+)_{12}(L_e)_{21}) \frac{2/3\alpha}{(M_\Lambda + M_\Sigma)/2} + \right.$$

$$\left. V_{td}(C_{21} + C_{22}(L_e)_{21}) \frac{1 - 2/3\alpha}{M_\Lambda} \right|^2 \ , \tag{69}$$

while the widths of the $p \to \pi\nu^\alpha$ decays are:

$$\Gamma(p \to \pi\nu_\mu) = \frac{m_p}{32\pi m_n^2} F_w^2 \left(\frac{\Delta I}{I}\right)^2 \left(\frac{v_2}{\sqrt{2}}\right)^2 \bar{m}_t^2 |V_{ub} V_{td}|^2 \left| C_{12} + C_{22}(L_d^+)_{12} \right|^2 \ , \tag{70}$$

[2]necessary matrix elements are presented in the end of this section

Table 2: An order of magnitude estimates of the proton partial life times in the units of 10^{32} years.

	$C_{22}=0$	$C_{22}=2\lambda_s$
$p\to K\nu_\mu$	~ 10	~ 3
$p\to K\nu_e$	~ 200	~ 200
$p\to \pi\nu_\mu$	~ 10	~ 10
$p\to \pi\nu_e$	~ 300	~ 400
$p\to K^0\mu^+$	~ 10	~ 0.01
$p\to K^0e^+$	~ 1	~ 1
$p\to \pi^0\mu^+$	~ 0.05	~ 0.05
$p\to \pi^0e^+$	~ 1	~ 1

$$\Gamma(p\to\pi\nu_e)=\frac{m_p}{32\pi m_n^2}F_w^2\left(\frac{\Delta I}{I}\right)^2\left(\frac{v_2}{\sqrt{2}}\right)^2\bar{m}_t^2|V_{ub}V_{td}|^2\times$$
$$\left|C_{12}(L_e)_{21}+C_{21}(L_d^+)_{12}+C_{22}(L_e)_{21}(L_d^+)_{12}\right|^2\ , \tag{71}$$

where $\bar{m}_t=2.4\cdot 180$ GeV (an artifact of the A_L definition).

Crucial for the suppression of the $p\to K\nu$ decay mode is the form of matrix A. We had study the renormalization of the matrix A from GUT to the SUSY breaking scale and it appears that its form is not changed, so the results presented in this section are valid also for the case when the renormalization effects are taken into account.

Proton decays $p\to Kl^+$ and $p\to\pi e^+$ in our model are described by the box diagrams shown on Fig. 2f and 2h and the vertex diagram shown on Fig. 2g amplitude of which is proportional to $\Delta I/I$ for the same reason as that described by the diagram of Fig. 2a (see the beginning of this section). Vertex diagram shown on Fig. 2e produces b quark, so it is irrelevant for proton decay. For proton decay widths we obtain:

$$\Gamma(p\to K\mu)=\frac{(m_p^2-m_K^2)^2}{32\pi m_p^3}\left(\frac{1-2\alpha}{M_\Sigma}\right)^2F_w^2\left(\frac{v_2}{\sqrt{2}}\right)^2\bar{m}_t^2|V_{ub}|^2\times$$

$$\left|\sqrt{\frac{m_u}{m_t}}\left(2C_{22}+V_{us}C_{12}+2C_{21}(L_e)_{12}+C_{12}(L_d^+)_{21}+C_{12}(L_u^+)_{21}\right)\right.$$

$$-\left(\frac{\Delta I}{I}\right) V_{ts}\left(C_{12}+C_{22}(L_u^+)_{12}\right)\Big|^2 \ , \tag{72}$$

$$\Gamma(p\to Ke)=\frac{(m_p^2-m_K^2)^2}{32\pi m_p^3}\left(\frac{1-2\alpha}{M_\Sigma}\right)^2 F_w^2\left(\frac{v_2}{\sqrt{2}}\right)^2 \bar{m}_t^2|V_{ub}|^2\Big|2\sqrt{\frac{m_u}{m_t}}\,(C_{21}+$$

$$C_{22}(L_e)_{21})-\left(\frac{\Delta I}{I}\right) V_{ts}\left(C_{12}(L_e)_{21}+C_{21}(L_u^+)_{12}+C_{22}(L_u^+)_{12}(L_e)_{21}\right)\Big|^2 \ , \tag{73}$$

$$\Gamma(p\to\pi\mu)=\frac{1}{64\pi m_p}F_w^2\left(\frac{v_2}{\sqrt{2}}\right)^2\bar{m}_t^2|V_{ub}|^2\times$$

$$\left|\sqrt{\frac{m_u}{m_t}}\,(2C_{12}+C_{22}V_{cd})-\left(\frac{\Delta I}{I}\right) V_{td}\left(C_{12}+C_{22}(L_u^+)_{12}\right)\right|^2 \ , \tag{74}$$

$$\Gamma(p\to\pi e)=\frac{1}{64\pi m_p}F_w^2\left(\frac{v_2}{\sqrt{2}}\right)^2\bar{m}_t^2|V_{ub}|^2\times$$

$$\Big|2\sqrt{\frac{m_u}{m_t}}\left(C_{12}(L_e)_{21}+C_{21}(L_d^+)_{12}+C_{22}(L_d^+)_{12}(L_e)_{21}\right)-$$

$$\left(\frac{\Delta I}{I}\right) V_{td}\left(C_{12}(L_e)_{21}+C_{21}(L_u^+)_{12}+C_{22}(L_u^+)_{12}(L_e)_{21}\right)\Big|^2 \ . \tag{75}$$

The desirable at GUT scale relations $\frac{\lambda_\mu}{\lambda_s}=3$ or -3 in our model occur for $C_{22}\equiv\tilde{b}_1=0$ or $C_{22}=2\lambda_s$. In the first case the strong suppression of the $p\to K\mu$ mode will occur. In numerical estimates we consider both these cases.

Proton partial lifetimes for $C_{22}=2\lambda_s$ and $C_{22}=0$ and for the values of the parameters from Table 3 are presented in Table 2 . As we see proton partial lifetimes with emission of neutrino for values $(m_{\tilde{q}},m_{\tilde{W}})=(500\ \mathrm{GeV},500\ \mathrm{GeV})$ in both cases $C_{22}=2\lambda_s$ and $C_{22}=0$ are compatible with the experimental data. For the case $C_{22}=2\lambda_s$ the decays $p\to K\mu$ and $p\to\pi\mu$ are too fast and we have to change the masses of SUSY particles. For example for $(m_{\tilde{q}},m_{\tilde{W}})=(1\ \mathrm{TeV},100\ \mathrm{GeV})$ we get $\tau(p\to K\mu)=10^{32}$ years and $\tau(p\to\pi\mu)=10^{33}$ years.For the case $C_{22}=0$ the $p\to\pi\mu$ mode dominates and for $(m_{\tilde{q}},m_{\tilde{W}})=(600\ \mathrm{GeV},100\ \mathrm{GeV})$ $\tau(p\to\pi\mu)=10^{32}$ years.

At the end of this section let us present the results of the calculation of the matrix elements which contribute into proton decay in our model:

$$\langle\nu K|(us)(\nu d)|p\rangle=\frac{\tilde{\beta}G}{(M_\Lambda+M_\Sigma)/2}\frac{2\sqrt{2}\alpha}{3}(\nu P_L p)K \ , \tag{76}$$

Table 3: Numerical values of parameters which were used in the estimates of the proton partial lifetimes.

$m_{\tilde{W}}$	$m_{\tilde{q}}$	m_u	m_d	m_s	m_c	m_t
500 GeV	500 GeV	3.6 MeV	6 MeV	151 MeV	1.3 GeV	180 GeV
V_{ub}	V_{ts}	V_{td}	$\sin 2\beta$	$A_S^h(\tilde{t})$	$M_{\tilde{H}_3}$	$\alpha_3(M_Z)$
0.003	0.05	0.01	0.51	1.9	10^{16} GeV	0.120

$$\langle \nu K|(ud)(\nu s)|p\rangle = \frac{\tilde{\beta}G}{M_\Lambda}\sqrt{2}(1-2/3\alpha)(\nu P_L p)K \quad , \tag{77}$$

$$\langle \nu \pi|(ud)(d\nu)|p\rangle = \frac{\tilde{\beta}G}{M_n}\sqrt{2}(\nu P_L p)\pi \quad , \tag{78}$$

$$\langle lK|(us)(ul)|p\rangle = \frac{\tilde{\beta}G}{M_\Sigma}\sqrt{2}(1-2\alpha)(lP_L p)K \quad , \tag{79}$$

$$\langle l\pi|(ud)(ul)|p\rangle = \frac{\tilde{\beta}G}{M_n}(lP_L p)\pi \ . \tag{80}$$

6 Discussions

One of the most appealing next step after minimal standard $SU(3)\times SU(2)\times U(1)$ model is Grand Unification Theory. Both theoretical argument (hierarchy problem) and experimental measurements (values of electroweak mixing angle and α_s) prefer, select or point out on SUSY GUT. Simplest variant is SU(5) SUSY GUT. However, minimal version of the model has two drawbacks: too short proton life time and famous ratio: $m_d/m_s = m_e/m_\mu$. Proton decay proceed through operators with $d=5$. Dominant decay mode is $p\to K\nu$ with life time of the order of 10^{28} years (compare with experimental bound $\tau(p\to K\nu) > 10^{32}$years). From the ratio of electron and muon masses we get $m_s/m_d = 200$ which contradicts phenomenological value $m_s/m_d = 20 \div 30$.

Both these dissapointing results follow from one source: Yukawa interactions of quark-lepton (super)multiplets with Higgs fields in the minimal

SU(5). Beyond minimal model Yukawa interactions are less constrained. In our approach pattern of quark and lepton masses and CKM matrix is explained by the higher dimension operators through which first two fermion generations get their masses. Now predictions for proton life time differ drastically from that of minimal SUSY SU(5) GUT. Since only third generation fermions interacts with 5 and $\bar{5}$ Higgs fields in the same way as in minimal model, operators with $d = 5$ involve these heavy particles which can not participate in proton decay. Bare third generation particles get admixtures from first two generations which are small. This smallness guarantee smallness of the deviation of CKM matrix from unity. In this way proton decay is also suppressed. For scalar quark masses $m_{\tilde{q}} = 500$ GeV we obtain: $\tau(p \to K\nu) \sim 10^{32}$years which is 4 orders of magnitude better than in minimal model. It is interesting to note that $p \to K\nu$ decay proceed due to large mass of top quark which manifest itself in noticeable mass difference between $\tilde{t}$ and $\tilde{u}$, $\tilde{c}$. To suppress proton decay further two possibilities exists. First, straightforward one uses heavier squarks. In this way $p \to K\mu$ mode dominates over additionally suppressed ($\sim m_t^2/m_{\tilde{q}}^2$) $p \to K\nu$ mode and for $m_{\tilde{q}} = 1.2$ TeV and $m_{\tilde{W}} = 100$ GeV we get $\tau(p \to K\mu) = 10^{32}$years. Second possibility is intimately connected with desirable ratio $m_\mu/m_s \approx \pm 3$ at GUT scale. There are two possibilities to get this ratio in our model: to form the 45-plet from the product of Higgs fields $24 \times \bar{5}$ (famous Georgi-Jarlskog construction) or to compose 45-plet and 5-plet in a special way. In the first case contribution to $d = 5$ operator is of the order of λ_s while in the second case it is suppressed. It equals zero for $m_\mu/m_s = 3$ and is less then $0.1\lambda_s$ for experimentally acceptable choice $m_\mu/m_s = 2.6 - 3.4$. In this way even for $m_{\tilde{q}} = 600$ GeV and $m_{\tilde{W}} = 100$ GeV we get $\tau_p = 10^{32}$ years.

Search for proton decay at Superkamiokande detector should define future fate of the suggested scenario.

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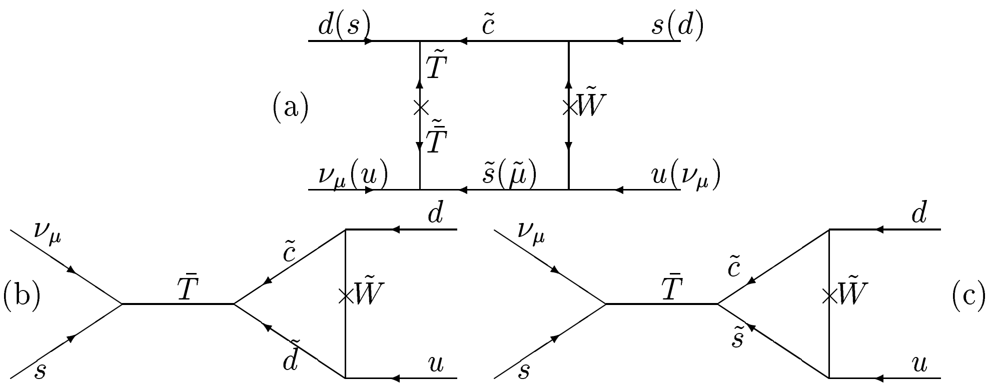

Figure 1: This picture represents Feynman diagrams which contribute into the leading in minimal SUSY SU(5) decay mode $p \to K^+\nu_\mu$. Sum of the contribution of Fig. 1b and Fig. 1c equals zero.

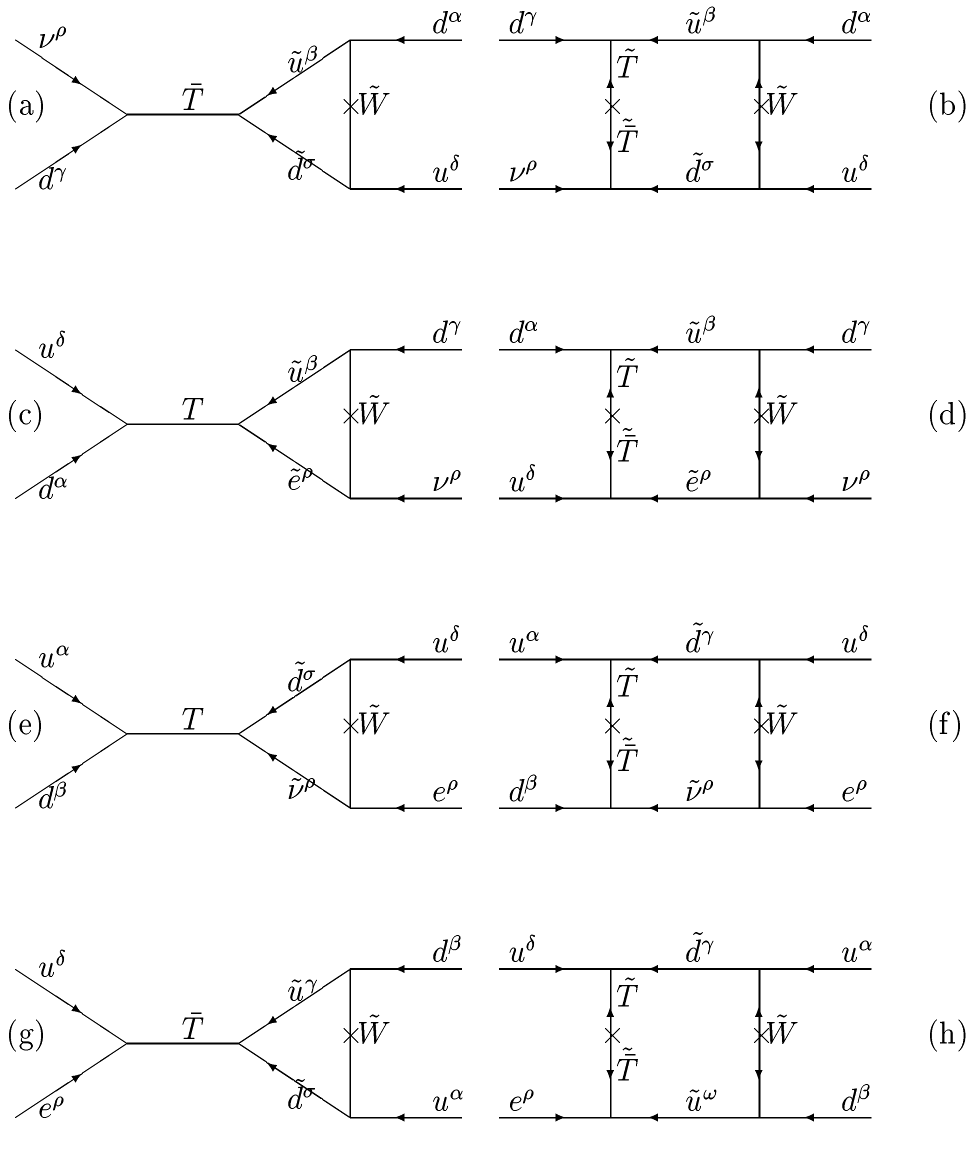

Figure 2: All possible diagrams which describe proton decay through wino dressing.