# UPPER BOUND ON THE PROTON LIFETIME AND THE MINIMAL NON-SUSY GRAND UNIFIED THEORY

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**Abstract.** In this talk I show that it is possible to find an upper bound on the total proton lifetime. I conclude that the simplest realistic non-supersymmetric grand unified theory is based on $SU(5)$ with a Higgs sector composed of $5_H$, $24_H$ and $15_H$. I discuss the possibility to test this GUT scenario at the next generation of proton decay experiments and future colliders through the production of light scalar leptoquarks.

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## INTRODUCTION

It is well-known that the decay of the proton is the most dramatic prediction coming from matter unification [1]. For this reason we believe that the best way to test the grand unified theories is through proton decay. In the first part of my talk I will discuss the possibility to find an upper bound on the proton lifetime, which is crucial to understand the possibility to test the different minimal grand unified models with the standard model matter content.

As is well-known the minimal Georgi-Glashow model [2] is the simplest grand unified theory. However, this model is not realistic. In the second part of my talk I will present the minimal realistic extension of the Georgi-Glashow theory. I will show that this model could be tested at future proton decay experiments since the upper bound on the proton decay lifetime is $\tau_p \leq 1.4 \times 10^{36}$ years. This model predicts light scalar leptoquarks, therefore for the first time we have the possibility to test a GUT model at future hadron colliders, particularly at the LHC.

## UPPER BOUND ON THE TOTAL PROTON LIFETIME

There are several relevant operators to the decay of the proton. In non-supersymmetric grand unified theories we have the gauge and Higgs $d = 6$ contributions. It is well-known that the gauge contributions are the most important in this context. In supersymmetric models the most important contributions are coming from the $d = 4$ and $d = 5$ operators (For details see [3]). As is well-known one can always forbid or suppress the $d = 4$, $d = 5$, and the Higgs $d = 6$ contributions. However, it is not possible to forbid the gauge contributions in grand unified models with the standard model matter content.

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Now, since those contributions are always present and are the least model dependent, the upper bound on the proton lifetime is coming from the minimization of the decay rate due to the presence of those operators. In order to minimize the decay rate due to the presence of gauge $d = 6$ contributions we have studied those in details. In the physical basis these operators are given in [4].

It is important to understand that it is difficult to predict the lifetime of the proton since we do not know all mixing matrices entering in the decay rates due to the presence of superheavy gauge bosons. Even in minimal models it is very difficult to predict all those matrices. Now, we would like to find the minimum of the decay rate. Let us study the case of grand unified theories based on $SU(5)$ gauge symmetry. In order to find a possible "minimum" of the decay rate in these theories, we studied two major cases [5]. In the first case there are no decays into a meson and antineutrinos, and in the second there are no decays into a meson and charged antileptons. We investigated those cases in detail, showing that the upper bound is coming from the first case [5]. Let us understand these results.

In order to set to zero all channels with antineutrinos we have to look for a model of fermion masses where the following conditions are valid [5]:

$$(V_1 V_{UD})^{1\alpha} = (U_C^\dagger D)^{1\alpha} = 0 \Longrightarrow U_C = DA^\dagger \quad \text{(C.I)} \tag{1}$$

$$V_2^{\beta\alpha} = (E_C^\dagger D)^{\beta\alpha} = 0 \Longrightarrow E_C = DB_1 \quad \text{(C.II)} \tag{2}$$

$$V_3^{\beta\alpha} = (D_C^\dagger E)^{\beta\alpha} = 0 \Longrightarrow D_C = EB_2 \quad \text{(C.III)} \tag{3}$$

with

$$A = \begin{pmatrix} 0 & 0 & e^{i\alpha} \\ \dots & \dots & 0 \\ \dots & \dots & 0 \end{pmatrix}, \; B_i = \begin{pmatrix} 0 & 0 & e^{i\beta_i} \\ 0 & e^{i\gamma_i} & 0 \\ e^{i\delta_i} & 0 & 0 \end{pmatrix} \tag{4}$$

and the upper bound on the proton lifetime reads as:

$$\tau_p \leq 6.0 \times 10^{39} \, \frac{(M_V/10^{16}\,\text{GeV})^4}{\alpha_{GUT}^2} \, (0.003\,\text{GeV}^3/\beta)^2 \,\text{years} \tag{5}$$

Notice that this expression is valid for a given value of the GUT scale and $\alpha_{GUT}$. Now, using the experimental lower bound ($\tau_p \geq 50 \times 10^{32}$ years) and the value $\beta = 0.003\,\text{GeV}^3$ for the matrix element, we can conclude that the lower bound on the GUT scale is $M_V > 3.04 \times 10^{14} \sqrt{\alpha_{GUT}}\,\text{GeV}$. Now, if we use the values for $\alpha_{GUT} = 1/39 - 1/25$ in the non-susy and susy case, respectively: $M_V > (4.9 - 6.1) \times 10^{13}\,\text{GeV}$ Notice that the lower bound on the GUT scale tells us that a non-SUSY $SU(5)$ could be consistent with the experimental bounds. In flipped $SU(5)$ theories it is possible to set to zero all proton decay channels at the same time [6]. Therefore, the above upper bound on the proton lifetime is also valid for $SO(10)$ theories.

Therefore we can conclude that the non-supersymmetric grand unified theories are still in agreement with the proton decay experiments. Now, since in future experiments the bounds on the proton decay experiments could be improved in two or three orders of magnitude, we are not sure about the possibility to test the supersymmetric grand unified theories through nucleon decay where the $d = 5$ operators are absent or suppressed. In other words, in this case the lifetime of the proton could be very large.

As we discussed before the non-susy theories could be realistic. Then, let us study the possibility to write down the simplest non-susy grand unified theory.

## THE MINIMAL REALISTIC EXTENSION OF THE GEORGI-GLASHOW MODEL

In the Georgi-Glashow model based on $SU(5)$ gauge symmetry [2] the Standard Model matter is unified in the $\bar{5}$ and 10 representations and the Higgs sector is composed of the $5_H$ and $24_H$. As it is well-known this model is not realistic since it is not possible to unify all gauge couplings, the neutrinos are massless, and we find the wrong relation $Y_D = Y_E^T$. Now, as we pointed out in reference [7], if we add the $15_H$ and use the higher-dimensional operators, we can write the minimal realistic extension of the Georgi-Glashow model, where it is possible to achieve unification, we can use the type II see-saw mechanism for neutrino masses and it is possible to find a consistent relation between the fermion masses in this context. We studied the unification constraints in detail [8]. The fields which help us to achieve unification are $\Sigma_3 = (1,3,0) \subset 24_H$, $\Phi_a = (1,3,1) \subset 15_H$, and $\Phi_b = (3,2,1/6) \subset 15_H$. In this model the maximal value for the unification scale is $M_{GUT} = 3.2 \times 10^{14}$ GeV, defined for $M_{\Sigma_8} = 10^5$ GeV, $M_{\Sigma_3} = M_Z$, $M_{\Phi_a} = 130$ GeV, $M_{\Phi_b} = 242$ GeV, and $\alpha_{GUT} = 1/37.3$. See references [7] and [8] for details. Now, using the maximal value for the GUT scale the upper bound on the proton lifetime reads as:

$$\tau_p \leq 1.4 \times 10^{36} \text{ years} \tag{6}$$

Therefore we can say that this model could be tested or ruled out at the next generation of proton decay experiments. Recently, we studied the simplest renormalizable realistic $SU(5)$ model which Higgs sector is composed of $5_H$, $24_H$, and $45_H$ [9], and we concluded that the proton lifetime can be very large. Therefore, we can say that the only realistic non-SUSY $SU(5)$ that we can verify in near future is the model presented in reference [7].

Now, if we study carefully the results in [7], we see that once we impose the proton decay constraints we get an upper bound on the scalar leptoquark mass, which is basically $M_{\Phi_b} \leq 10^8$ GeV. Also it was noticed that in the case of the most natural implementation of the type II see-saw mechanism (large $M_{\Phi_a}$) the mass of the scalar leptoquarks ($\Phi_b$) is in the phenomenologically interesting region $(O(10^2 - 10^3)GeV)$. Then, we can conclude that our GUT scenario has a potential to be tested at the next generation of collider experiments, particularly at the LHC.

## SUMMARY

In this talk I have discussed the possibility to find an upper bound on the proton decay lifetime. The conservative upper bound on the total proton decay valid for any grand unified model with the standard model matter content is given by:

$$\tau_p \leq 6.0 \times 10^{39} \, \frac{(M_V/10^{16}\,\mathrm{GeV})^4}{\alpha_{GUT}^2} \, (0.003\,\mathrm{GeV}^3/\beta)^2 \,\mathrm{years} \tag{7}$$

where $M_V$ is the mass of the superheavy gauge bosons and $\beta$ is the value of the matrix element. I conclude that the non-supersymmetric grand unified theories with low unification scale ($M_V > 4.9 \times 10^{13}\,\mathrm{GeV}$) are not ruled out by the bounds coming from the proton decay searches.

It is shown that the minimal non-supersymmetric grand unified theory is the modified Georgi-Glashow model with Higgs sector composed of $5_H$, $24_H$, and $15_H$. This scenario can be tested at future proton decay experiments ($\tau_p \leq 1.4 \times 10^{36}$ years) and future colliders, particularly at LHC, through the production of scalar leptoquarks $\Phi_b$.

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