

THE MASS OF THE STOP IN THE NMSSM

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Abstract: *The Next Minimal Supersymmetric Standard Model (NMSSM) is one of the expansion models of the Standard Model (SM) to solve some outstanding problems that Standard Model has not yet solved. The particles superpartner in SM are now interesting searched for on accelerators. The stops are superpartner of the top quarks and are predicted to be easy to find because there are the smaller masses in the partners of the quarks. In this paper, we calculate the stop mass and evaluates the influencing parameters with the hope that experimentation will soon find these new particles.*

Keywords: *NMSSM, stop, CP violation.*

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1. INTRODUCTION

The Next Minimal Supersymmetric Standard Model (NMSSM) is the supersymmetric extension of the Standard Model (SM) [6] to solve some outstanding problems of SM as well as previous minimal supersymmetric expansion such as: Solve hierarchy problem, CP violation problem, μ problem... [1, 2, 3, 10]. Extending supersymmetry in a minimal way requires adding 2 Higgs SU (2), pairs H_u, H_d , the vacuum average value (vevs) of H_u, H_d generates the mass of particles of quarks up, quark down and the charge of lepton corresponding [5] but the problem is the mass parameter of supersymmetry μ which has th hierarchy of M_{SUSY} and it is called the μ problem MSSM.

A simple way to solve this problem is to create the one mass term μ (supersymmetry) in a similar way to generating mass of quark particle and lepton mass in SM: the mass term μ is made up of by Yukawa interaction of H_u and H_d [5,6] with the scalar field and to ensure the hierarchy there must be the vevs of the scalar field deduced from the soft SUSY breaking condition. When the μ parameter has no quantum number of the group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ [1,2,3,5], the input field is S single groups [4,9] (complex scalar components of chiral scalar superfield \hat{S}) that is The Next Minimal Supersymmetric Standard Model (NMSSM) and is also denoted $(M + 1)$ SSM [1,5].

By giving the the hierarchies for the parameter μ of MSUSY that forms the theoretical basis for NMSSM: the two Higgs complex scalar of H_u and H_d of MSSM must be contained in the components of the chiral superfield and complement the fermion interaction SU(2) includes Ψ_d and Ψ_u . The Lagrangians of MSSM may contain supersymmetry mass term of fields, squared masses μ^2 of $|H_u|^2$ and $|H_d|^2$ are always positive, Dirac masses μ of Ψ_d and Ψ_u . The presence of the supersymmetry mass term is proportional to the μ term in Lagrangian, a soft SUSY that breaks the mass term $B_\mu H_u H_d$ may also appear when a soft SUSY breaks the dimension parameter B of mass [5,6]

The lagrange of NMSSM will be built to include two parts as the supersymmetry lagrange and the soft symmetry breaking lagrange.

The Higg potential V in the NMSSM model has the form: [4]

$$V = V_F + V_D + V_S \quad (1)$$

$$\text{Here [4,7]: } V_D = \frac{g_2^2}{8} (H_1^+ \bar{\sigma} H_1 + H_2^+ \bar{\sigma} H_2)^2 + \frac{g_1^2}{8} (|H_2|^2 - |H_1|^2)^2,$$

$$V_F = |\lambda|^2 \left[(|H_1|^2 + |H_2|^2) |N|^2 \right] + |k|^2 |N|^4 - (\lambda k^* H_1 H_2 N^{*2} + H.c),$$

$$V_S = m_{H_1}^2 |H_1|^2 + m_{H_2}^2 |H_2|^2 + m_N |N|^2 - \left(\lambda A_\lambda H_1 H_2 N + \frac{1}{3} k A_k N^3 + H.c \right),$$

with g_1 and g_2 being the U(1) and SU(2) gauge coupling constants respectively, $\bar{\sigma} = (\sigma^1, \sigma^2, \sigma^3)$ are the Pauli matrices.

To break the spontaneous symmetry and the mass calculation of particles in the model, we can be the expression of the doublet (H_1, H_2) and singlet N following forms: [4]

$$H_1 = \begin{pmatrix} v_1 + S_1 + iA \sin \beta \\ \sin \beta C^{*+} \end{pmatrix},$$

$$H_2 = \begin{pmatrix} \cos \beta C^+ \\ v_2 + S_2 + iA \cos \beta \end{pmatrix}, \quad (2)$$

$$N = (x + X + iY),$$

where S_1, S_2, X are the scalar Higgs fields, A and Y are the pseudoscalar Higgs fields, C^+ is the charged Higgs field, v_1, v_2 and x are the vevs of H_1, H_2 and N respectively.

Instead of the lagrang we obtain a squared matrix of stop masses A in the basis \bar{t}_R, t_L [5,8]:

$$A = \begin{pmatrix} m_T^2 + h_t^2 v_u^2 - (v_u^2 - v_d^2) \frac{g_1^2}{3} & h_t (A_t v_u - \mu_{eff} v_d) \\ h_t (A_t v_u - \mu_{eff} v_d) & m_{Q_3}^2 + h_t^2 v_u^2 + (v_u^2 - v_d^2) \left(\frac{g_1^2}{12} - \frac{g_2^2}{4} \right) \end{pmatrix} \quad (3)$$

2. THE MASS OF THE STOP

To calculate the square of the mass of the stop, we use the matrix cross method (3). The components on the diagonal will correspond to the square of the mass of the stop, ie we obtain two superpartners of the top quark.

The unita matrix, orthogonal V make cross the matrix A according to the formula

$$VA V^{-1} = A' \quad (4)$$

Orthogonal V is calculated which has form

$$V = \begin{pmatrix} Z + \sqrt{\Delta} & Z - \sqrt{\Delta} \\ 1 & 1 \end{pmatrix} \quad (5)$$

Here

$$\Delta = \left[\left\{ \frac{1}{2}(m_{Q_3}^2 - m_T^2) + \left(\frac{2}{3}m_W^2 - \frac{5}{12}m_Z^2 \right) \cos 2\beta \right\}^2 + m_t^2 (A_t^2 + \lambda^2 s^2 \cot^2 \beta + 2A_t \lambda s \cot \beta \cos \phi_t) \right]^{\frac{1}{2}}$$

$$Z = \frac{1}{2}(m_T^2 - m_{Q_3}^2) + v^2 \cos 2\beta \left(\frac{5}{24}g_1^2 - \frac{1}{8}g_2^2 \right)$$

The matrix of the squared mass of the stop after being crossed has the form

$$A' = \begin{pmatrix} a_{11} & 0 \\ 0 & a_{22} \end{pmatrix} \quad (6)$$

Here [4]:

$$a_{11} = \left[\begin{matrix} m_t^2 + \frac{1}{2}(m_{Q_3}^2 + m_T^2) \\ + \frac{m_Z^2}{4} \cos 2\beta \end{matrix} \right] - \left[\begin{matrix} \left\{ \frac{1}{2}(m_{Q_3}^2 - m_T^2) + \left(\frac{2}{3}m_W^2 - \frac{5}{12}m_Z^2 \right) \cos 2\beta \right\}^2 \\ + m_t^2 (A_t^2 + \lambda^2 s^2 \cot^2 \beta + 2A_t \lambda s \cot \beta \cos \phi_t) \end{matrix} \right]^{\frac{1}{2}}$$

$$a_{22} = \left[\begin{matrix} m_t^2 + \frac{1}{2}(m_{Q_3}^2 + m_T^2) \\ + \frac{m_Z^2}{4} \cos 2\beta \end{matrix} \right] + \left[\begin{matrix} \left\{ \frac{1}{2}(m_{Q_3}^2 - m_T^2) + \left(\frac{2}{3}m_W^2 - \frac{5}{12}m_Z^2 \right) \cos 2\beta \right\}^2 \\ + m_t^2 (A_t^2 + \lambda^2 s^2 \cot^2 \beta + 2A_t \lambda s \cot \beta \cos \phi_t) \end{matrix} \right]^{\frac{1}{2}}$$

with: $\cos \phi_t = -1$; $m_Z^2 = (g_1^2 + g_2^2) \frac{v^2}{2}$; $m_W^2 = \frac{g_2^2 v^2}{2}$; $\tan \beta = \frac{v_u}{v_d}$; m_T^2 ; $m_{Q_3}^2$ are the square of

the mass of the 3rd generation; $v = \sqrt{v_u^2 + v_d^2} \approx 175 GeV$ [4].

Based on the evaluation conditions of parameters of NMSSM according to the references [4]: $2 \leq \tan \beta \leq 40$; $0 < A_t \leq 1 TeV$; $0 < m_{Q_3} \leq 1 TeV$; $0 < m_T \leq 1 TeV$; $\mu_{eff} = \lambda s \geq 100 GeV$ we can evaluate the mass of the stop.

3. THE INFLUENCE OF THE PARAMETERS ON THE MASS OF THE STOP

To evaluate the influence of $\tan\beta$ on stop mass, we choose the following parameters [4]:

$$A_t = 807\text{GeV}; m_t = 494\text{GeV}; m_{Q3} = 667\text{GeV}; \mu_{\text{eff}} = 100\text{GeV}.$$

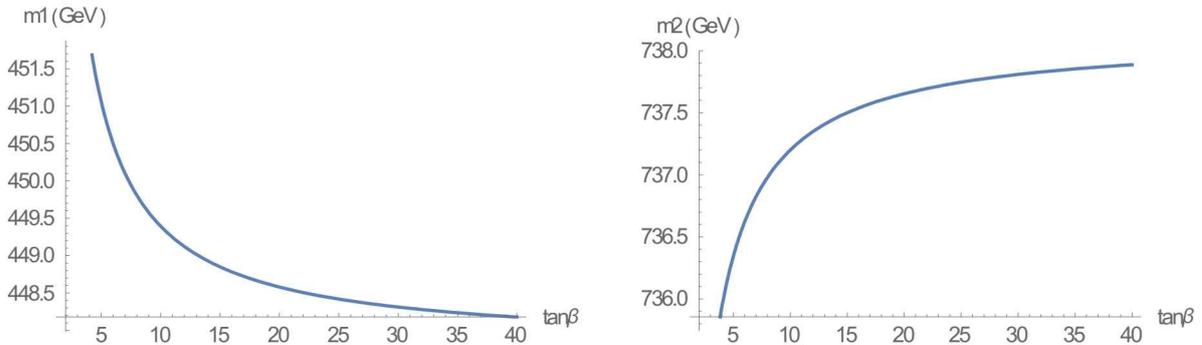


Figure 1. Influence of $\tan\beta$ on stop mass

From the result in Figure 1 we see that the stop mass m_1 is around 448.5 - 451.5 GeV, and the stop mass m_2 is around 736 - 738 GeV. The influence of $\tan\beta$ on the mass of 2 stops is small, in the variable range of $\tan\beta$ from 5 - 40, the mass of these stops changes only around 0.27% - 0.3%.

To evaluate the influence of A_t on stop mass, we choose the following parameters [4]: $\tan\beta = 5$; $m_t = 494\text{GeV}$; $m_{Q3} = 667\text{GeV}$; $\mu_{\text{eff}} = 100\text{GeV}$.

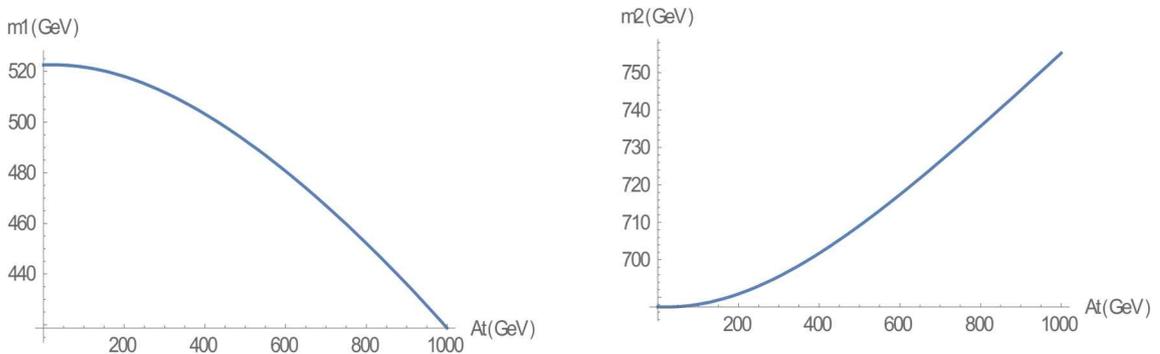


Figure 2. Influence of A_t on stop mass

From the result in Figure 2 we see that the stop mass m_1 is around 440 - 520 GeV, and the stop mass m_2 is around 700 - 750 GeV. The influence of A_t on the mass of 2 stops is not small, in the variable range of A_t from 0 - 1 TeV, the stop mass m_1 changes about 15%, stop m_2 changes about 6%. To evaluate the influence of m_{Q3} on stop mass, we choose the following parameters [4]: $A_t = 807\text{GeV}$; $\tan\beta = 5$; $m_t = 494\text{GeV}$; $\mu_{\text{eff}} = 100\text{GeV}$.

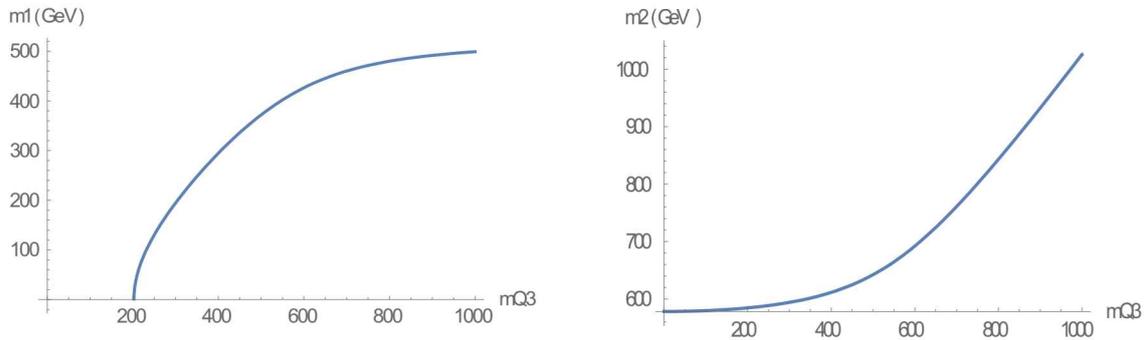


Figure 3. Influence of m_{Q3} on stop mass

From the result in Figure 3 we see that the stop mass m_1 is around 100 – 500GeV, and the stop mass m_2 is around 600 - 1000GeV. The influence of m_{Q3} on the mass of 2 stops is very large, in the variable range of m_{Q3} from 0 – 1TeV, the stop mass m_1 changes about 80%, stop m_2 changes about 40%. To evaluate the influence of m_t on stop mass, we choose the following parameters [4]: $A_t = 807\text{GeV}$; $\tan\beta = 5$; $m_{Q3} = 667\text{GeV}$; $\mu_{\text{eff}} = 100\text{GeV}$.

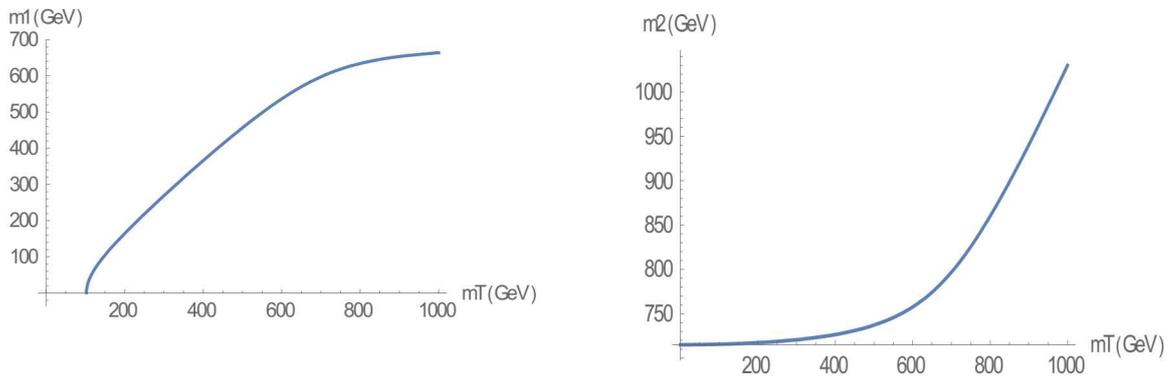


Figure 4. Influence of m_t on stop mass

From the result in Figure 4 we see that the stop mass m_1 is around 100 – 700GeV, and the stop mass m_2 is around 750 - 1000GeV. The influence of m_t on the mass of 2 stops is very large, in the variable around of m_t from 0 – 1TeV, the stop mass m_1 changes about 85%, stop m_2 changes about 25%.

To evaluate the influence of m_t on stop mass, we choose the following parameters [4]: $A_t = 807\text{GeV}$; $\tan\beta = 5$; $m_t = 494\text{GeV}$; $m_{Q3} = 667\text{GeV}$.

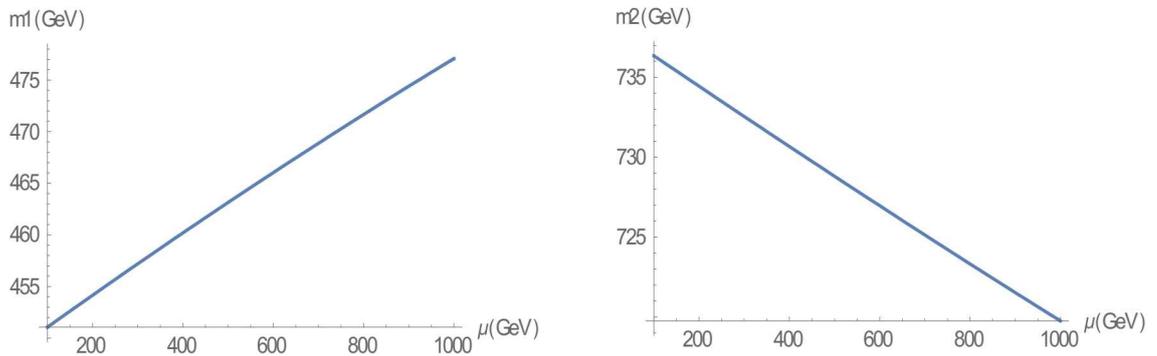


Figure 5. Influence of μ_{eff} on stop mass

From the result in Figure 5 we see that the stop mass m_1 is around 455 – 475 GeV, and the stop mass m_2 is around 725 - 735 GeV. The influence of μ_{eff} on the mass of 2 stops is small, in the variable around of m_T from 0 – 1 TeV, the stop mass m_1 changes about 4%, stop m_2 changes about 1.3%.

4. CONCLUSION

From the study to evaluate the mass of stops in NMSSM and the effect of the parameters in the model on the mass of these stops, we obtain the following main results:

1. The mass of two stops is significantly different. The mass of the lighter stop will be in the around 400-500 GeV. The mass of the heavier stop will be in the around 700-750 GeV.
2. The influence of parameters m_t and m_{Q3} on stop mass is very large. The influence of the parameters μ_{eff} and $\tan\beta$ on the stop mass are very small. The A_t parameter has influence a stop in the about 10%.
3. The influence of the parameters on lighter stop mass will be greater than the heavier stop mass.

These evaluations will hopefully give us a better understanding of the mass of the stops as well as provide value for measuring or calculating the physical effects related to stops in NMSSM.

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KHỐI LƯỢNG CỦA STOP TRONG NMSSM

Tóm tắt: Mô hình chuẩn siêu đối xứng gần tối thiểu (NMSSM) là một trong những mô hình mở rộng của mô hình chuẩn (SM) nhằm giải quyết những vấn đề còn tồn tại của SM. Các bạn đồng hành siêu đối xứng trong SM hiện đang được tích cực tìm kiếm trên các máy gia tốc. Các hạt stop là bạn đồng hành siêu đối xứng của quark top và được dự đoán là dễ tìm kiếm hơn vì có khối lượng nhỏ nhất trong số các bạn đồng hành siêu đối xứng của các hạt quark. Trong bài báo này, chúng tôi tính toán khối lượng của stop có đánh giá các tham số ảnh hưởng với hy vọng góp phần cùng thực nghiệm sớm tìm ra các hạt mới này.

Từ khoá: NMSSM, stop, vi phạm đối xứng CP.