Hidden Sector Assisted 125 GeV Higgs

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ATLAS, CMS reported the excesses of events for $\gamma\gamma$, ZZ^*, $WW^* \longrightarrow$ 4 leptons around 125 GeV.

They seemingly imply the the presence of the Higgs with 125 GeV mass at 3σ level.

Higgs mass in the MSSM

- at tree level

$$m_h^2 < M_Z^2 \cos^2 2\beta$$

- LEP bound: $m_h^2 > 114$ GeV.
- By including the radiative corrections, the Higgs mass can be raised above 100 GeV.

Radiative Corr. to m_h^2 in the MSSM

$$\Delta m_h^2 = (3/4\pi^2)\,(y_t M_t)^2 \sin^2\beta\ \log(M_t^2 + m_t^2 / M_t^2)$$

(y_t: top quark Yukawa coupling, M_t : top quark mass, m_t : S-top mass)

For a large radiative correction to the Higgs mass,

the S-top should be quite heavy.

(a few TeV for m_h=125 GeV)

Radiative Corr. to m_h^2 in the MSSM

The other piece of ΔV_{CW}'' contributes to the renormalization of m_{2h}^2.

One of the extremum conditions with the MSSM Higgs pot. reads

$$m_{2h}^2 = m_{12}^2 \cot\beta + (M_Z^2/2)\cos 2\beta$$

$$-(3y_t^2/8\pi^2)[\, m_t^2\{\log(m_t^2/\Lambda^2)-1\}-M_t^2\{\log(M_t^2/\Lambda^2)-1\}\,]$$

A large m_t (a few TeV) requires a fine-tuning (0.1%) among the soft parameters to fit M_Z .

"Little Hierarchy Problem"

Radiative Corr. to m_h^2 in the MSSM (mixing eff.)

Large mixing between the L- and R-hnd. S-tops through the "A-term" is helpful for raising m_h:

$$\Delta m_h^2 \approx (3/4\pi^2)\,(y_t M_t)^2 \sin^2\beta \left[\log(m_t^2/M_t^2) + (X_t/m_t)^2 \{1 - (X_t/m_t)^2/12\} \right]$$

$$X_t = A_t - \mu \cot\beta$$

The maximal mixing [$(X_t/m_t)^2 = 6$]
can push m_h up to 135 GeV. But, ...

Higgs mass in the NMSSM

- promote the MSSM μ term to $\lambda S H_u H_d$ in the superpot., introducing a singlet S.

- The Higgs mass can be raised to

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \lambda^2 v_H^2 \sin^2 2\beta + \Delta m_h^2$$

- But λ is restricted by the Landau pole constraint:

$$\lambda < 0.7$$

- For $m_t = O(100)$ GeV, $0.5 < \lambda < 0.7$, $1 < \tan\beta < 3$.

4^{th} family

- By introducing extra order one Yukawa coupling of extra unknown matter, 125 GeV Higgs mass can be explained without a serious fine-tuning.

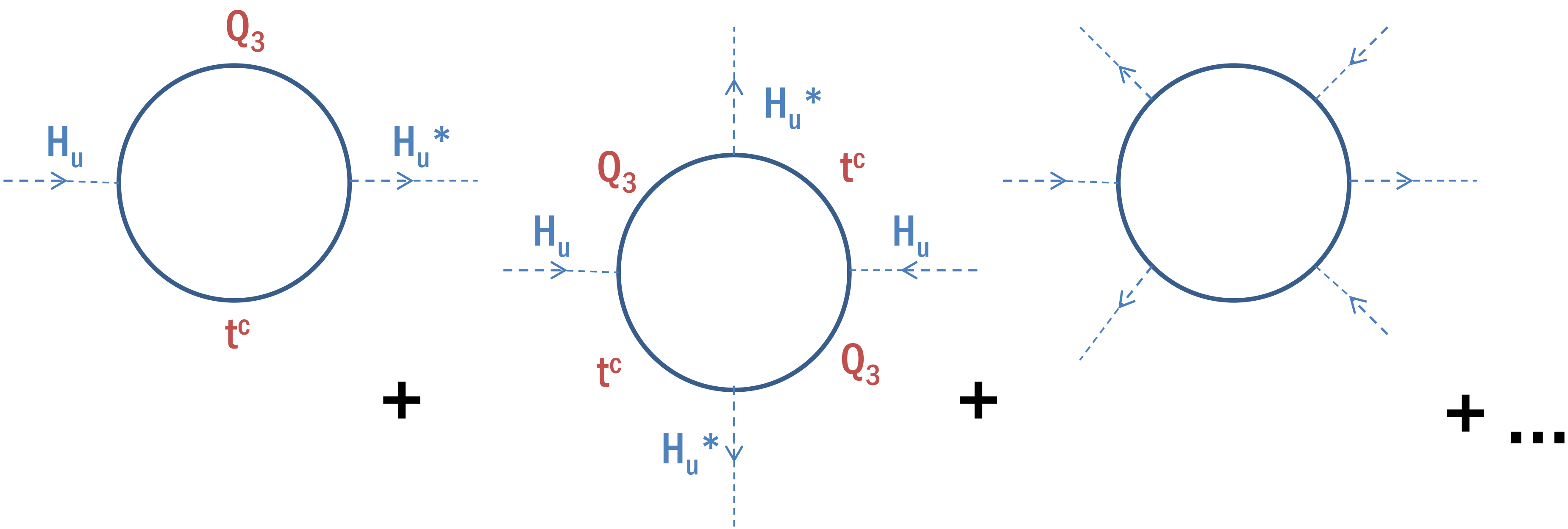
- But introduction of new colored particles with order one Yukawa couplings would exceedingly affect

1. the production rate of $gg \to h$ and also
2. the decay rate of $h \to \gamma\gamma$ at the LHC.

$\longrightarrow$ immoderate **deviation** from the **SM prediction**

Can the Radiative Correction be enhanced by MSSM singlets?

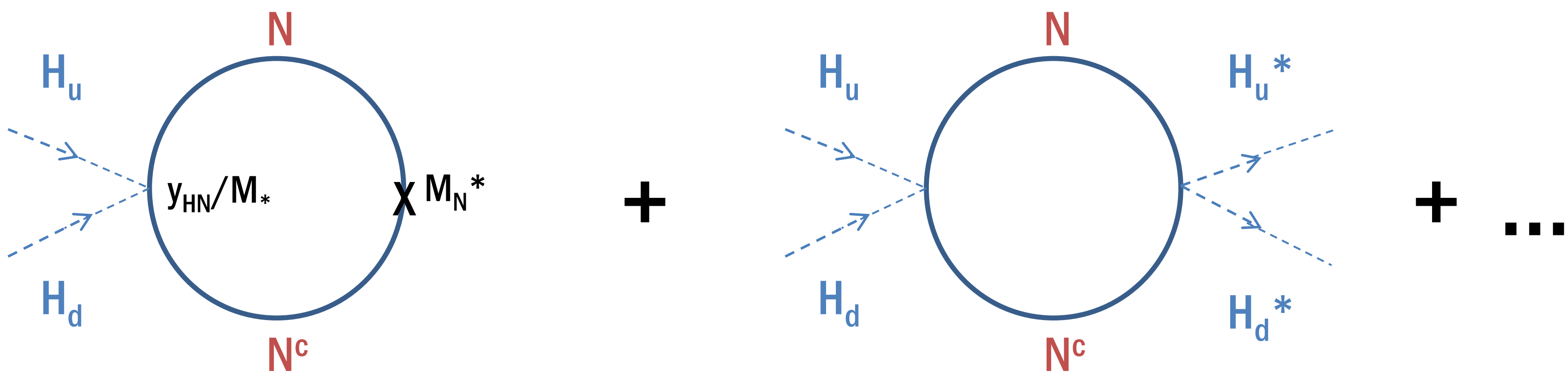
1-loop Effective Potential in the MSSM



+ bosonic loops

$$y_t\, H_u Q_3 t^c$$

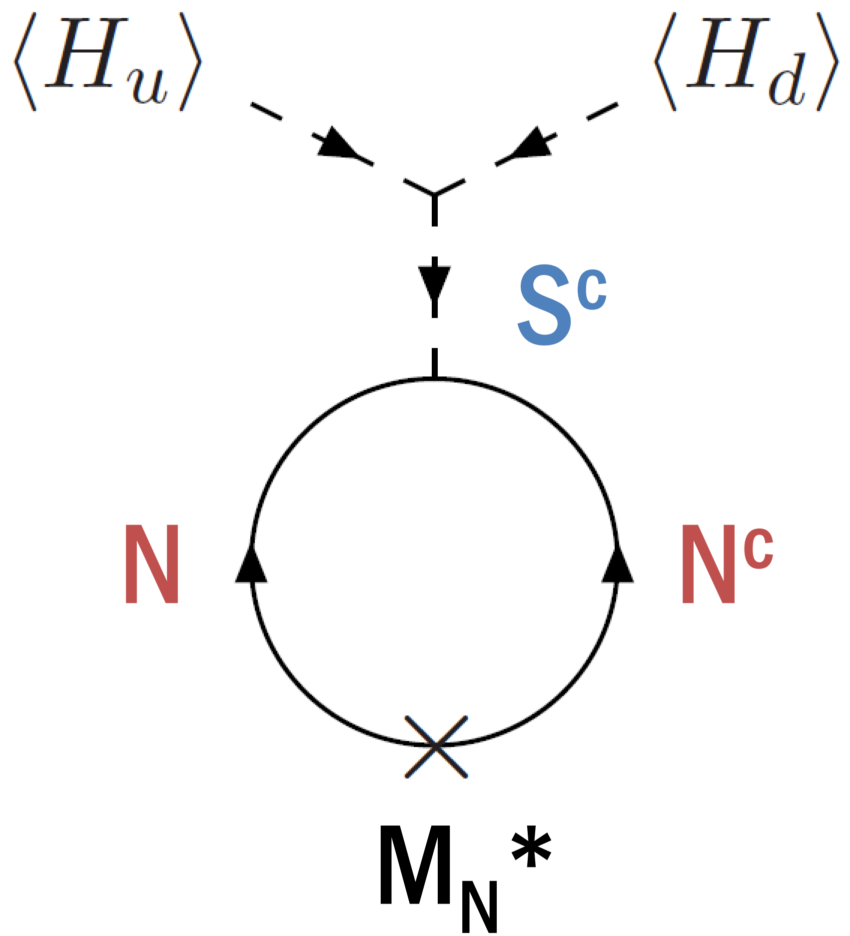
1-loop Effective Potential by SM Singlets



+ bosonic loops

$$(y_{HN}/M_*)\, H_u H_d N N^c + M_N\, N N^c$$

1-loop Effective Potential by SM Singlets

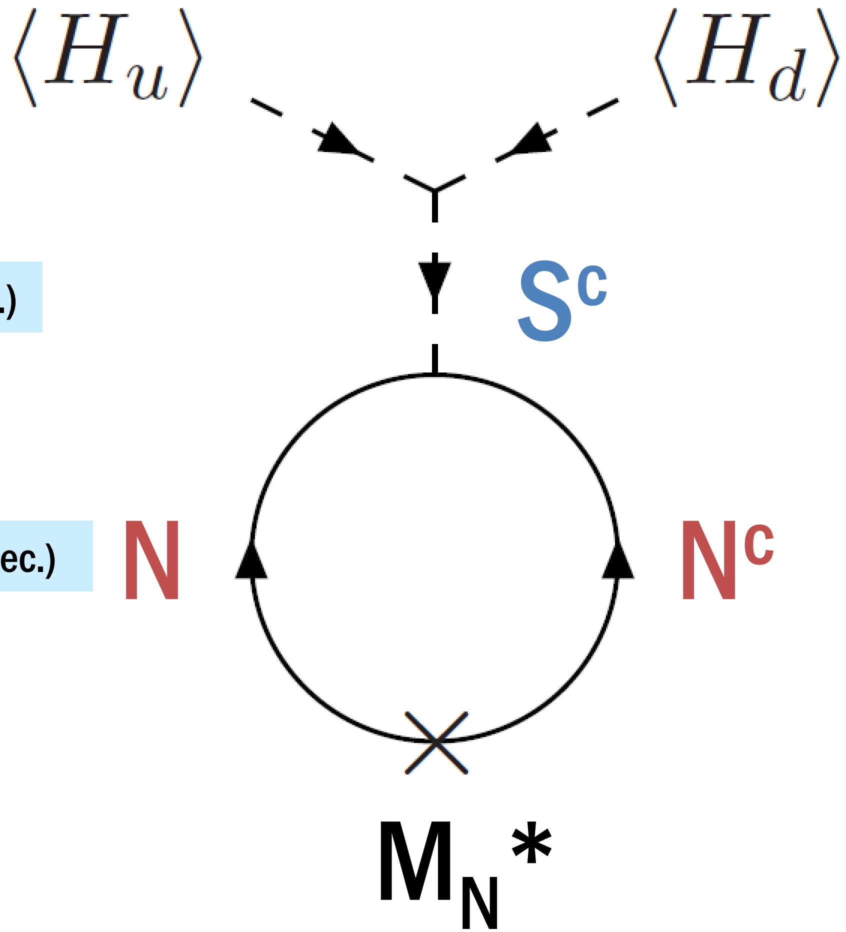


1-loop Effective Potential by SM Singlets

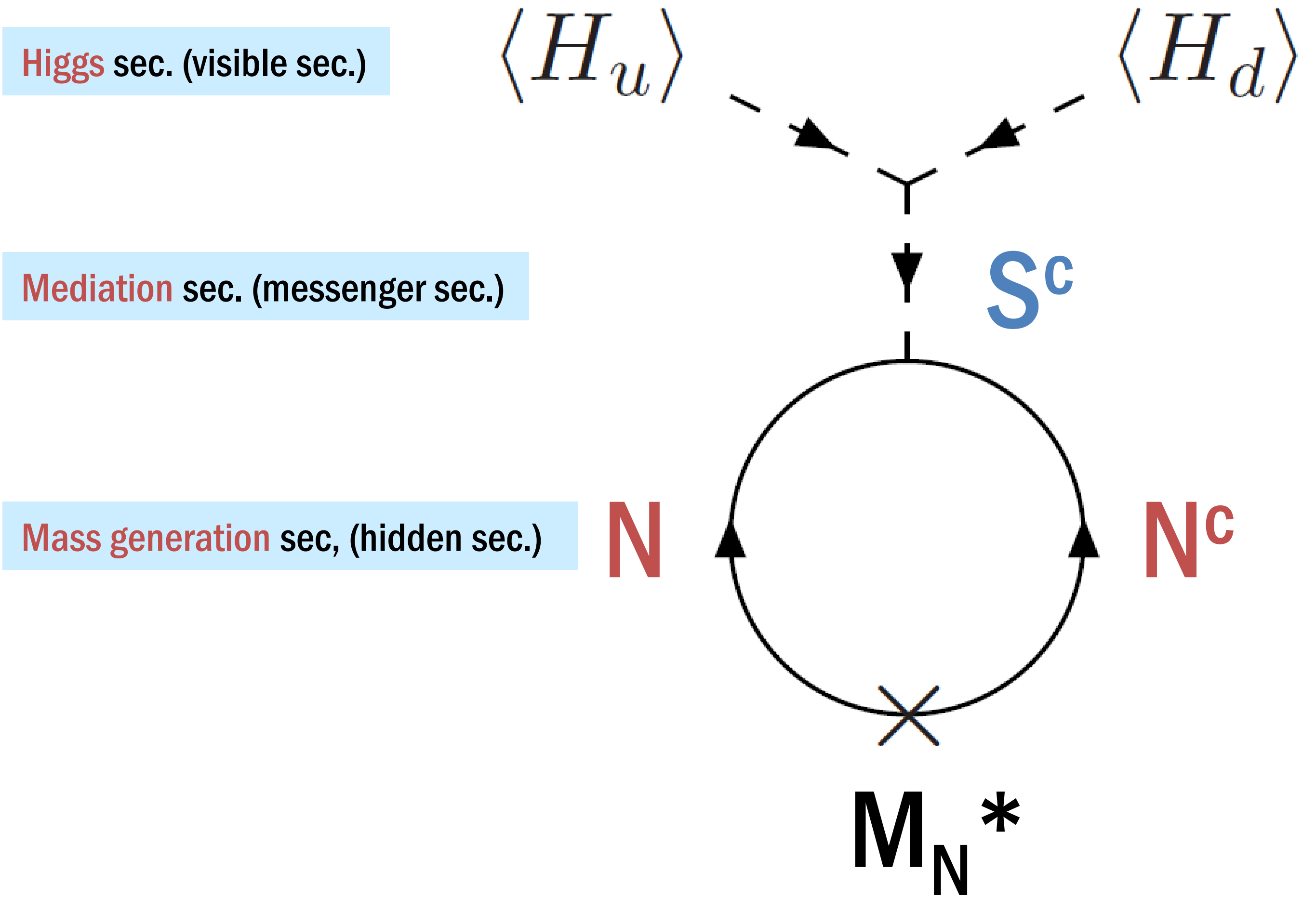
Higgs sec. (visible sec.)

Mediation sec. (messenger sec.)

Mass generation sec, (hidden sec.)



1-loop Effective Potential by SM Singlets



$W_{eff} = \mu H_u H_d$

$+ y_H S H_u H_d$

$+ M_S S S^c$

$+ y_N S^c N N^c$

$+ M_N N N^c$

A singlet extension of the MSSM

Introducing neutral fields under SM, $\{S, S^c\}$, $\{N, N^c\}$,
where $\{N, N^c\}$ are n-dim. Rep. of a (large) Hidden gauge group.

Visible sec. Messenger sec. Hidden sec.

$$W = y_H S H_u H_d + M_S S S^c + y_N S^c N N^c + M_N N N^c + W_{MSSM} \ (\mu \text{ term included})$$

$y_H < O(1)$, $y_N \sim O(1)$

y_N does NOT blow up at higher energies.

A singlet extension of the MSSM

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$$W = y_H S H_u H_d + M_S S S^c + y_N S^c N N^c + M_N N N^c + W_{MSSM} \text{ (}\mu\text{ term included)}$$

$y_H < O(1)$, $y_N \sim O(1)$ M_S , $M_N < 1$ TeV , e.g. by G.-M. mech.

A singlet extension of the MSSM

At the min. of the potential,

$$< S > \approx \text{(soft para.)} \times < H_u H_d >$$

$$< S^c > \approx -(y_H/M_S) < H_u H_d >$$

$$\text{SUSY mass}^2 \text{ of } \{N, N^c\} = [\, M_N - (y_H y_N/M_S) < H_u H_d >]^2$$

$$\approx M_N - 2\,(y_H y_N M_N/M_S) < H_u H_d >$$

→ insert it in the C.-W. pot.

Radiative Corr. to m_h^2 by the Singlets

$$\Delta m_h^2 = (n/4\pi^2)(y_N M_N/M_S)^2 (y_H^2 v_H^2 \sin^2 2\beta) \log(M_N^2 + m_N^2/M_N^2)$$

Δm_h^2 can be **enlarged** by n , $(y_N M_N/M_S)^2$, etc.

Compared with the case of the MSSM:

$$\Delta m_h^2|_{top} = (3/4\pi^2)\,(y_t M_t)^2 \sin^2\beta \;\; \log(M_t^2 + m_t^2/M_t^2)$$

(y_t: top quark Yukawa coupling, M_t : top quark mass, m_t : S-top mass)

Radiative Corr. to m_h^2 by the Singlets

$$\Delta m_h^2 = (n/4\pi^2)(y_N M_N/M_S)^2 (y_H^2 v_H^2 \sin^2 2\beta) \log(M_N^2 + m_N^2/M_N^2)$$

Note:

- Above M_S, $\Delta V(H)$ can NOT be a local op. any longer.
- y_N ($\sim O(1)$) does NOT blow up at higher energies.

Radiative Corr. to m_h^2 by the Singlets

The other piece of ΔV'' contributes to the renormalization of m_{12}^2.

One of the extremum conditions becomes

$$-2m_{12}^2 = (m_{1h}^2 - m_{2h}^2)\tan 2\beta + M_Z^2 \sin 2\beta$$

$$-(ny_H/4\pi^2)(y_N M_N/M_S)\left[m_N^2\{\log(m_N^2/\Lambda^2)-1\} - M_N^2\{\log(M_N^2/\Lambda^2)-1\} \right]$$

Radiative Corr. to m_h^2 by the Singlets

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$$-2m_{12}^2 = (m_{1h}^2 - m_{2h}^2) \tan 2\beta + M_Z^2 \sin 2\beta$$
$$-(n y_H/4\pi^2)(y_N M_N/M_S)\left[m_N^2\{ \log(m_N^2/\Lambda^2)-1 - M_N^2\{ \log(M_N^2/\Lambda^2)-1\} \right]$$

Compared with the MSSM/4th family scenario,

$$\Delta m_h^2 = (3/4\pi^2)\, (y_t M_t)^2 \sin^2\beta \;\log(M_t^2 + m_t^2/M_t^2)$$

$$m_{2h}^2 = m_{12}^2 \cot\beta + (M_Z^2/2)\cos 2\beta$$
$$-(3y_t^2/8\pi^2)[m_t^2\{ \log(m_t^2/\Lambda^2)-1\} - M_t^2\{ \log(M_t^2/\Lambda^2)-1\}]$$

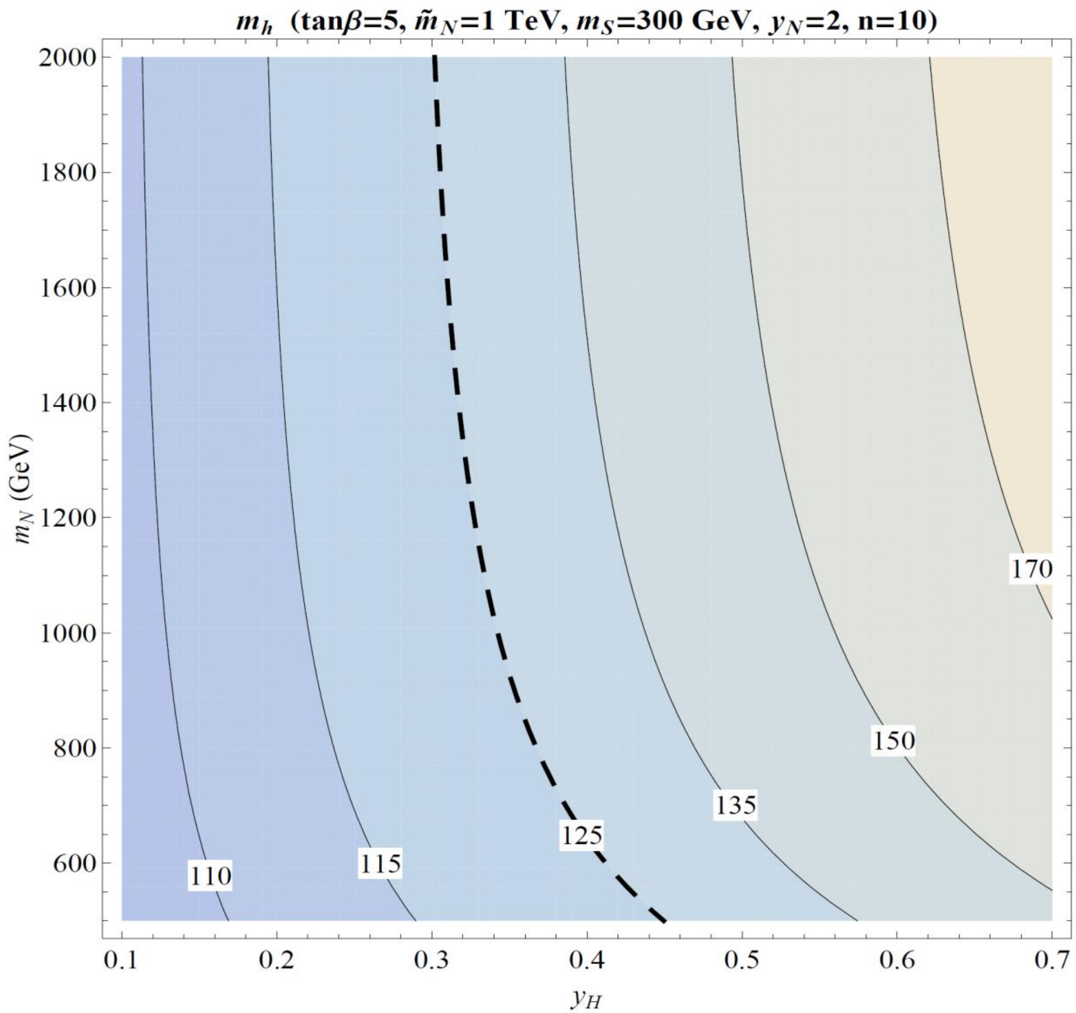

FIG. 2: Contour plots for the lightest Higgs mass m_h in the $y_H - m_N$ plane. Here we set $\Delta m_h|^2_{\text{top}} = (66\ \text{GeV})^2$, which corresponds to $\widetilde{m}_t \approx 500$ GeV at two-loop level, but turn off the mixing effect. The tree level contribution from the NMSSM is ignored. We fix the other parameters as shown in the figure. The thick dashed line corresponds to $m_h = 125$ GeV.

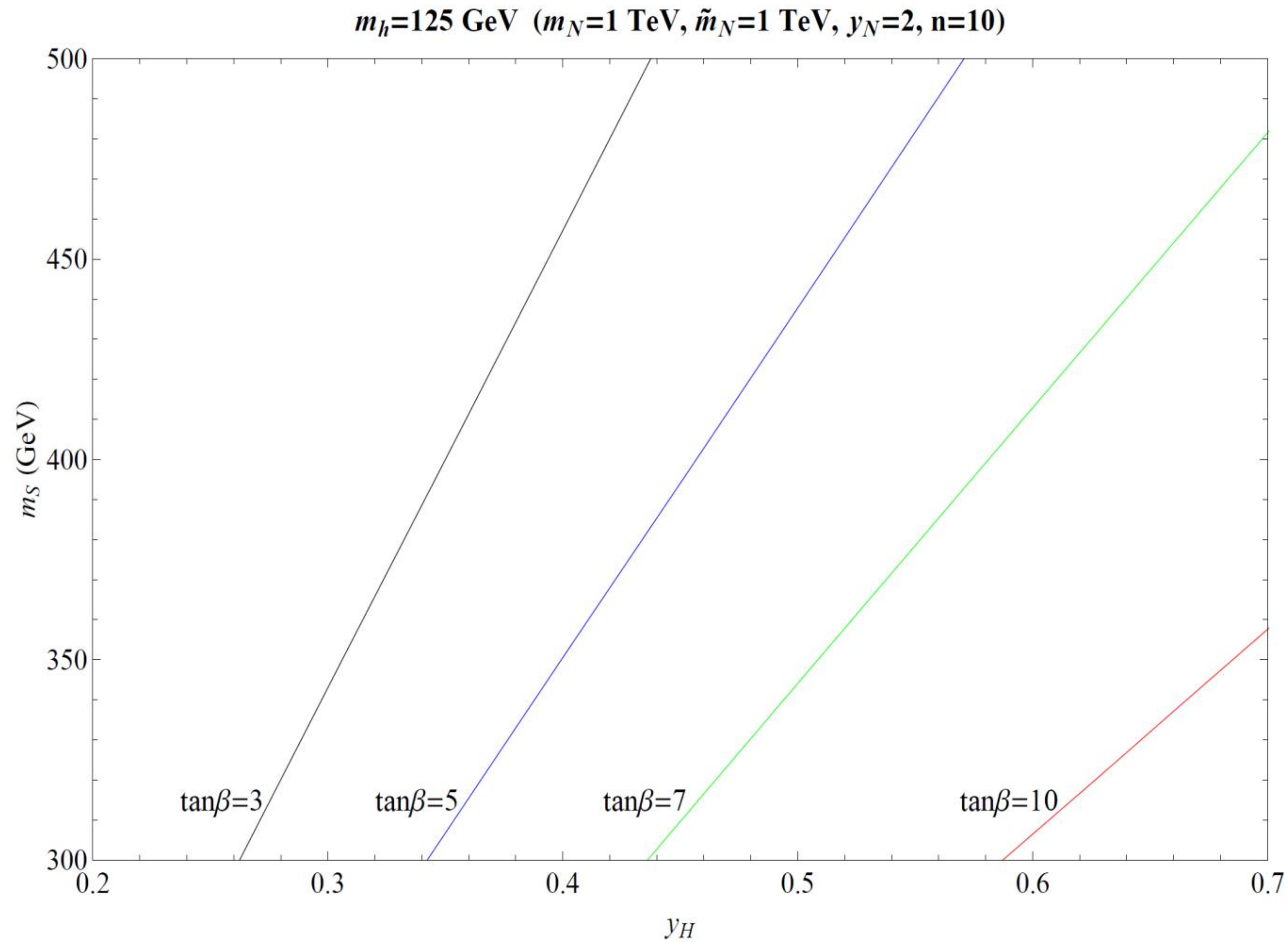

FIG. 3: Lightest Higgs mass $m_h = 125$ GeV lines for various $\tan\beta$s in the $y_H - m_S$ plane. Here we set $\Delta m_h|^2_{\rm top} = (66\ {\rm GeV})^2$, which corresponds to $\widetilde{m}_t \approx 500$ GeV at two-loop level, but turn off the mixing effect. The tree level contribution from the NMSSM is ignored. The other parameters are fixed as shown in the figure.

The Model

$$W_{\mathrm{UV}} = y_H S H_u H_d + y_N \overline{S} N \overline{N}$$

$$+ \frac{f_1}{M_P} \Sigma_1^2 H_u H_d + \frac{f_2}{M_P} \Sigma_2^2 N \overline{N} + \frac{f_3}{M_P} \Sigma_3^2 S \overline{S}$$

$$+ \frac{g_1}{M_P} \Sigma_3 \Sigma_1 \overline{\Sigma}_1^2 + \frac{g_2}{M_P} \Sigma_3 \Sigma_2 \overline{\Sigma}_2^2 + \frac{g_3}{M_P} \Sigma_3^2 \overline{\Sigma}_3^2$$

The Model

Superfields	H_u	H_d	N	$\overline{N}$	S	$\overline{S}$	Σ_1	Σ_2	Σ_3	$\overline{\Sigma}_1$	$\overline{\Sigma}_2$	$\overline{\Sigma}_3$
$\mathrm{U(1)_R}$	0	0	0	0	2	2	1	1	-1	1	1	2
$\mathrm{U(1)_{PQ}}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	-1	$\frac{1}{4}$	$-\frac{1}{2}$	$\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{8}$	$-\frac{1}{4}$

TABLE I. R and Pecci-Quinn charges of the superfields. The MSSM *matter* superfields carry the unit R charges, and also the PQ charges of 1/8. N and $\overline{N}$ are assumed to be proper n-dimensional vector-like representations of a hidden gauge group, under which all the MSSM fields are neutral. Σs and $\overline{\Sigma}$s carry some Z_2 charges.

The Model

The "A-terms" corresponding to the g_1, g_2, g_3 terms
and
the soft mass terms admit the VEVs,

$$< \Sigma_{1,2,3} > \sim < \Sigma^c_{1,2,3} > \sim (m_{3/2} M_P)^{1/2}$$

Then,
$f_i \Sigma_i^2 / M_P \sim m_{3/2}$. So μ, M_S, M_N are of EW scale.

The Model

The "A-terms" corresponding to the g_1, g_2, g_3 terms
and
the soft mass terms admit the VEVs,

$$< \Sigma_{1,2,3} > \sim < \Sigma^c_{1,2,3} > \sim (m_{3/2} M_P)^{1/2}$$

The domain wall problem can be avoided,
if $T_r < 10^9$ GeV.

Conclusion

- SUSY Higgs mass can increase through the radiative correction by 1 TeV scale Hidden sector fields, which can communicate with the Higgs via the messenger fields with 300 – 500 GeV masses.
- Even for $0.2 < y_H < 0.5$ or $3 < \tan\beta < 10$, 125 GeV Higgs mass can be naturally explained with relatively light S-top mass (≈ 500 GeV) but without their mixing effect.
- No serious fine-tuning because the mass para. for 125 GeV Higgs are all just around a few hundred GeV to 1 TeV.