Higgs mass from ~~SUSY~~ sector

Masaki Asano

(Bonn University)

Based on JHEP 1601(2016)066

MA, Y. Nakai, N. Yokozaki

Possibilities of Higgs mass from ~~SUSY~~ sector

- TeV ~~SUSY~~ ($m_{soft}^2 \sim F$)

$$W \supset \frac{B_\mu}{F} X H_d H_u \longrightarrow V \supset \left| \frac{B_\mu}{F} H_d H_u \right|^2$$

e.g., Brignole, Casas, Espinosa, Navarro ’03; …

- Hidden meson S of ~~SUSY~~ sector

$$W \supset \lambda_S\, S\, \mathrm{Hu\ Hd} \longrightarrow V \supset |\lambda_S\ \mathrm{Hu\ Hd}|^2$$

S works like NMSSM singlet.

Higgs mass from ~~SUSY~~ sector

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This talk

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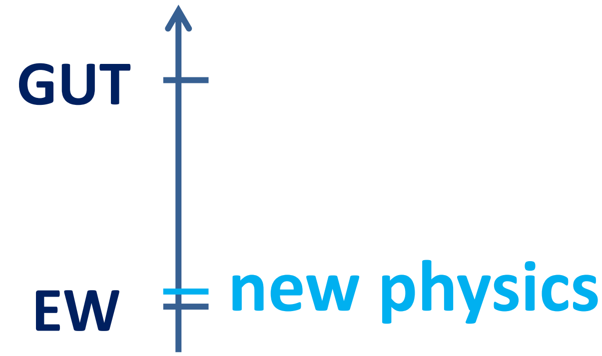
motivation

Motivation

- Λ_{EW} would be $\Lambda_{\text{new physics}}$.



- Why no dangerous Flavor-Changing Neutral Current?

(FCNC)

Gauge mediation

MSSM soft mass: flavor universal

→ naturally suppress the FCNC!!

$$\frac{q_i q_j q_k q_l}{\Lambda^2}$$

Motivation

But, Gauge Mediation predicts heavy MSSM!!

Small A term: $A_t \sim 0$ TeV $\quad V \supset A_t \tilde{t}_L \tilde{t}_R H_u$

↓

Radiative correction to Higgs mass is small:

$m_h = 125$ GeV → > 5 TeV SUSY ,

⇔ < 1 TeV m_{stop} is OK if $A_t \sim O(m_{stop})$

Heavy… ☹

Motivation

In this talk, we show a gauge mediation scenario with lighter SUSY particles by Hidden meson S (in ~~SUSY~~ sector)

$$W \supset \lambda_S \, S \, H_u \, H_d \longrightarrow \Delta m_h \sim \lambda_S^2 v^2 (\sin 2\beta)^2$$

- λ_S can be large: The perturbativity should keep only to the (low) confinement scale.

- S can get the soft mass (because S is also in ~~SUSY~~ sector)

In usual NMSSM extension, ~~SUSY~~ hardly mediates to the Singlet (because it's a SM singlet), which makes it difficult to achieve the correct EWSB.

model

At first, we introduce a known scenario of dynamical ~~SUSY~~ & gauge mediation

Gauge mediation Simplified

Murayama, Nomura '06

$$W = -m_i \bar{Q}^i Q^i + \frac{\lambda_{ijkl}}{M_{\rm Pl}} \bar{Q}^i Q^j \bar{Q}^k Q^l + \frac{\lambda_{ij}}{M_{\rm Pl}} \bar{Q}^i Q^j \bar{f} f + M \bar{f} f$$ **+ MSSM**

SUSY SU(Nc) QCD with Q^i, $\bar{Q}^i$ (i=1,...,Nf) $N_c + 1 \leq N_f < \frac{3}{2} N_c$

Gauge mediation Simplified

Murayama, Nomura ’06

~~SUSY~~ sector　　　　**Messenger**

$$W = -m_i \bar{Q}^i Q^i + \frac{\lambda_{ijkl}}{M_{\rm Pl}} \bar{Q}^i Q^j \bar{Q}^k Q^l + \frac{\lambda_{ij}}{M_{\rm Pl}} \bar{Q}^i Q^j \bar{f} f + M \bar{f} f$$ **+ MSSM**

SUSY SU(Nc) QCD with Q^i, $\bar{Q}^i$ (i=1,...,Nf) $N_c + 1 \leq N_f < \frac{3}{2} N_c$

$$W = -m_i \Lambda S^{ii} + \frac{\lambda_{ijkl}\Lambda^2}{M_{\rm Pl}} S^{ij} S^{kl} + \frac{\lambda_{ij}\Lambda}{M_{\rm Pl}} S^{ij} \bar{f} f + M \bar{f} f$$ **+ MSSM**

$$+ \bar{b}_i S^{ij} b_j - \frac{\det S^{ij}}{\Lambda^{N_f - 3}}$$

Seiberg ’94

Gauge mediation Simplified

Murayama, Nomura '06

~~SUSY~~ sector — Messenger

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$$+ \bar{b}_i S^{ij} b_j - \frac{\det S^{ij}}{\Lambda^{N_f - 3}}$$

Seiberg '94

Intriligator, Seiberg, Shih '06

At a local minimum, $b = \bar{b} = (\sqrt{m_1 \Lambda}$ 0 … 0), $S^{ij} = 0$

SUSY is broken: $F_{S^{ij}} = m_i \delta_{ij} \Lambda$ ($i, j \neq 1$)

SUSY vacuum is far from the origin of meson field.

SUSY breaking vacuum lifetime is long if $m_1 \ll \Lambda$

Gauge mediation Simplified

Murayama, Nomura '06

~~SUSY~~ sector — Messenger

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$$+ \bar{b}_i S^{ij} b_j - \frac{\det S^{ij}}{\Lambda^{N_f - 3}}$$

$$F_{S^{ij}} = m_i \delta_{ij} \Lambda \quad (\; i, j \neq 1 \;)$$

Avoid massless fermion of S^{ij}

Gauge Mediation

Our model

Composite NMSSM in Gauge mediation

MA, Nakai, Yokozaki ’15

In hidden sector, we consider

fields charged also the SM gauge.

$$W = m_{ij}\bar{Q}^i Q^j$$

$$\sum_{I=1}^{N_f} m_I Q_I \bar{Q}_I + m_\Psi \Psi_{\mathbf{5}} \bar{\Psi}_{\bar{\mathbf{5}}} \supset m_\Psi \Psi_u \bar{\Psi}_d$$

$SU(Nc)_H$ $\quad$ $SU(Nc)_H \times [SU(2) \times U(1)]_{SM}$

It can interact with MSSM Higgs.

$$+ \lambda_u H_u \bar{\Psi}_d Q_{N_f} + \lambda_d H_d \Psi_u \bar{Q}_{N_f}$$

$$m_\Psi > m_1 > m_2 > \cdots > m_{N_f-1} \gg m_{N_f}$$

At first, we integrate out Ψu,d

Composite NMSSM in Gauge mediation

MA, Nakai, Yokozaki ’15

After integrating out Ψu,d

1. A new higher dim. operator appears

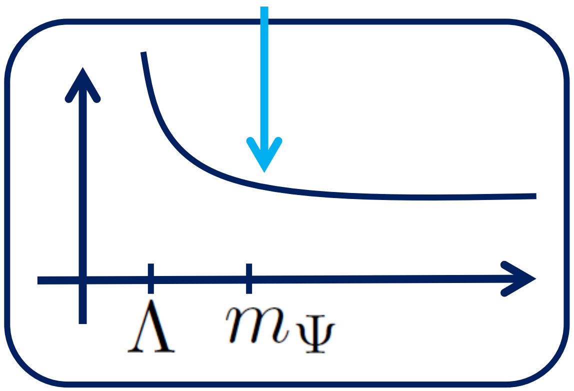
$$-\frac{\lambda_u \lambda_d}{m_\Psi} Q_{N_f} \bar{Q}_{N_f} H_u H_d$$

2. The confinement occurs

- Dynamical ~~SUSY~~ occurs.
- One light meson appears in low energy.

$$Q_{N_f} \bar{Q}_{N_f} \longrightarrow \Lambda\ S$$

Integrating out



Composite NMSSM in Gauge mediation

MA, Nakai, Yokozaki '15

Superpotential

$$W \supset m_{N_f} Q_{N_f} \bar{Q}_{N_f} + \frac{1}{M_0} Q_{N_f} \bar{Q}_{N_f} Q_{N_f} \bar{Q}_{N_f} \; \underline{- \frac{\lambda_u \lambda_d}{m_\Psi} Q_{N_f} \bar{Q}_{N_f} H_u H_d}$$

$$Q_{N_f} \bar{Q}_{N_f} \rightarrow \Lambda\, S$$

$$W \supset \xi_F S + \frac{1}{2} \mu' S^2 + \underline{\lambda_S S H_u H_d}$$

S^3 term is negligible because It's provided from higher dimensinal operator $(Q_{N_f} \bar{Q}_f)^3$

Composite NMSSM in Gauge mediation

MA, Nakai, Yokozaki ’15

Soft breaking term

- Usual gauge mediation contributions

$$m_{\rm soft} \sim \frac{g^2}{16\pi^2}\frac{F}{M}$$

- For such a light meson (small m_{N_f}), 2-loop correction can be important.

Giveon, Katz, Komargodski ’08

$$W_{\rm ISS} \supset \eta\, b_I S_{IJ} \bar{b}_J$$

$$V \supset m_S^2 |S|^2 \sim \eta^6 F/(16\pi^2)^2 |S|^2$$

⇨ F ~ (100 TeV)^2, favours low scale ~~SUSY~~.

Phenomenology

Composite NMSSM

$$W \supset \xi_F S + \frac{1}{2}\mu' S^2 + \lambda_S S H_u H_d$$

$$\mu_{\rm eff} \equiv \lambda_S v_S$$

Soft breaking term

$$V \supset m_S^2 |S|^2$$

+ usual gauge mediation

Higgs mass

$$M_{\rm H}^2 = \begin{pmatrix} M_{\rm H11}^2 & M_{\rm H12}^2 & M_{\rm H13}^2 \\ & M_{\rm H22}^2 & M_{\rm H23}^2 \\ & & M_{\rm H33}^2 \end{pmatrix}$$

$$\begin{aligned}
M_{\rm H11}^2 &\approx m_Z^2 (\cos 2\beta)^2 + \lambda_S^2 v^2 (\sin 2\beta)^2, \\
M_{\rm H22}^2 &\approx 2(\mu_{\rm eff}\mu' + \lambda_S \xi_F)/\sin 2\beta \\
&\quad + \left(m_Z^2 - \lambda_S^2 v^2\right)(\sin 2\beta)^2, \\
M_{\rm H33}^2 &\approx \mu'(-\lambda_S \xi_F + \lambda_S^2 v^2 \sin\beta/2)/\mu_{\rm eff}, \\
M_{\rm H12}^2 &\approx (-m_Z^2 + \lambda_S^2 v^2) \sin 4\beta/2, \\
M_{\rm H13}^2 &\approx \lambda_S v (2\mu_{\rm eff} - \mu' \sin 2\beta), \\
M_{\rm H23}^2 &\approx -\lambda_S v \mu' \cos 2\beta,
\end{aligned}$$

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m_h become large if the off-diagonal is small.

Composite NMSSM

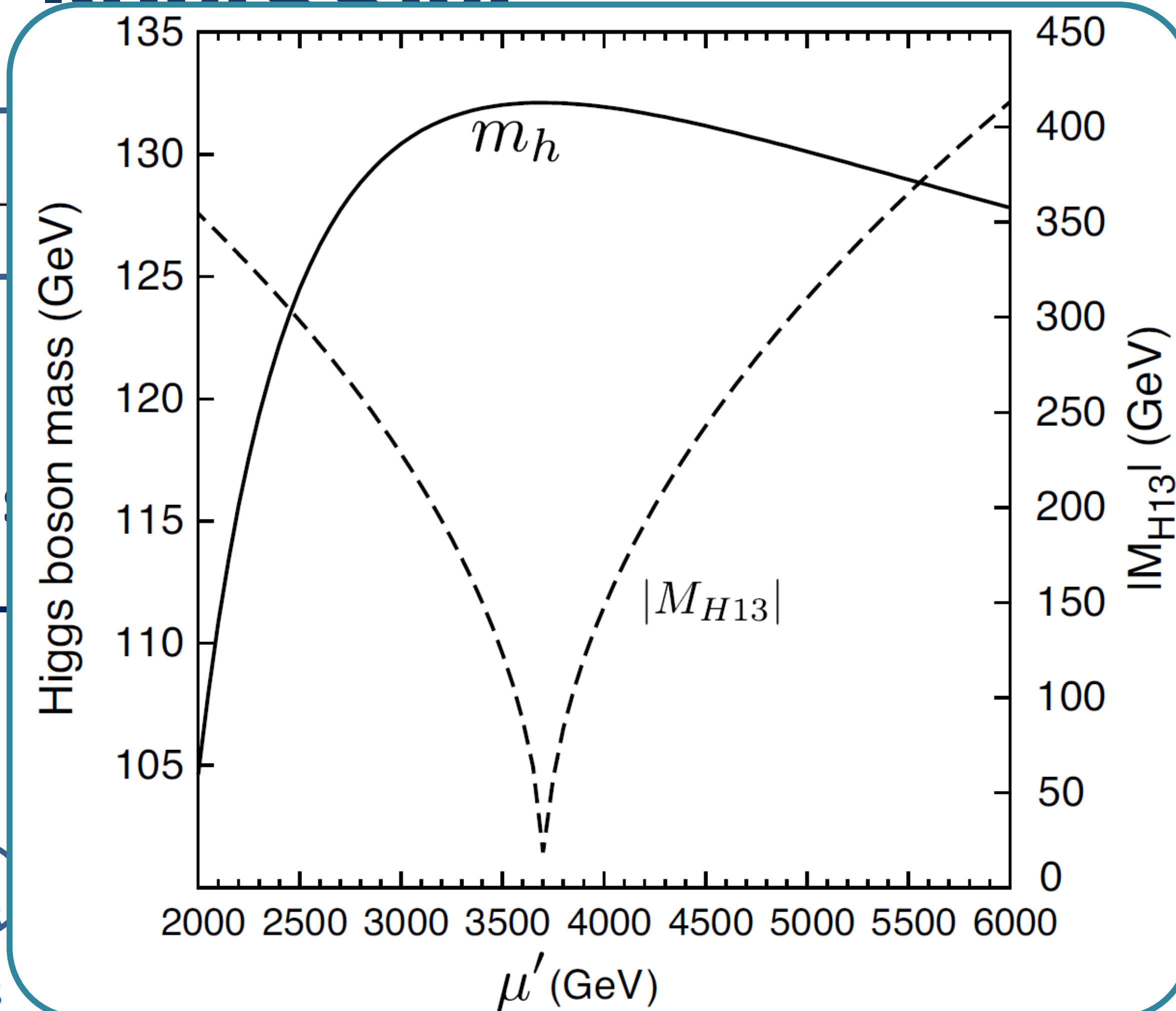
$$W \supset \xi_F S + \frac{1}{2}\mu' S^2 + \ldots$$

Soft breaking term

$$V \supset m_S^2 |S|^2$$

+ u

Higgs mass



$$M_H^2 = \begin{pmatrix} M_{H11}^2 & M_{H12}^2 & M_{H13}^2 \\ & M_{H22}^2 & M_{H23}^2 \\ & & M_{H33}^2 \end{pmatrix}$$

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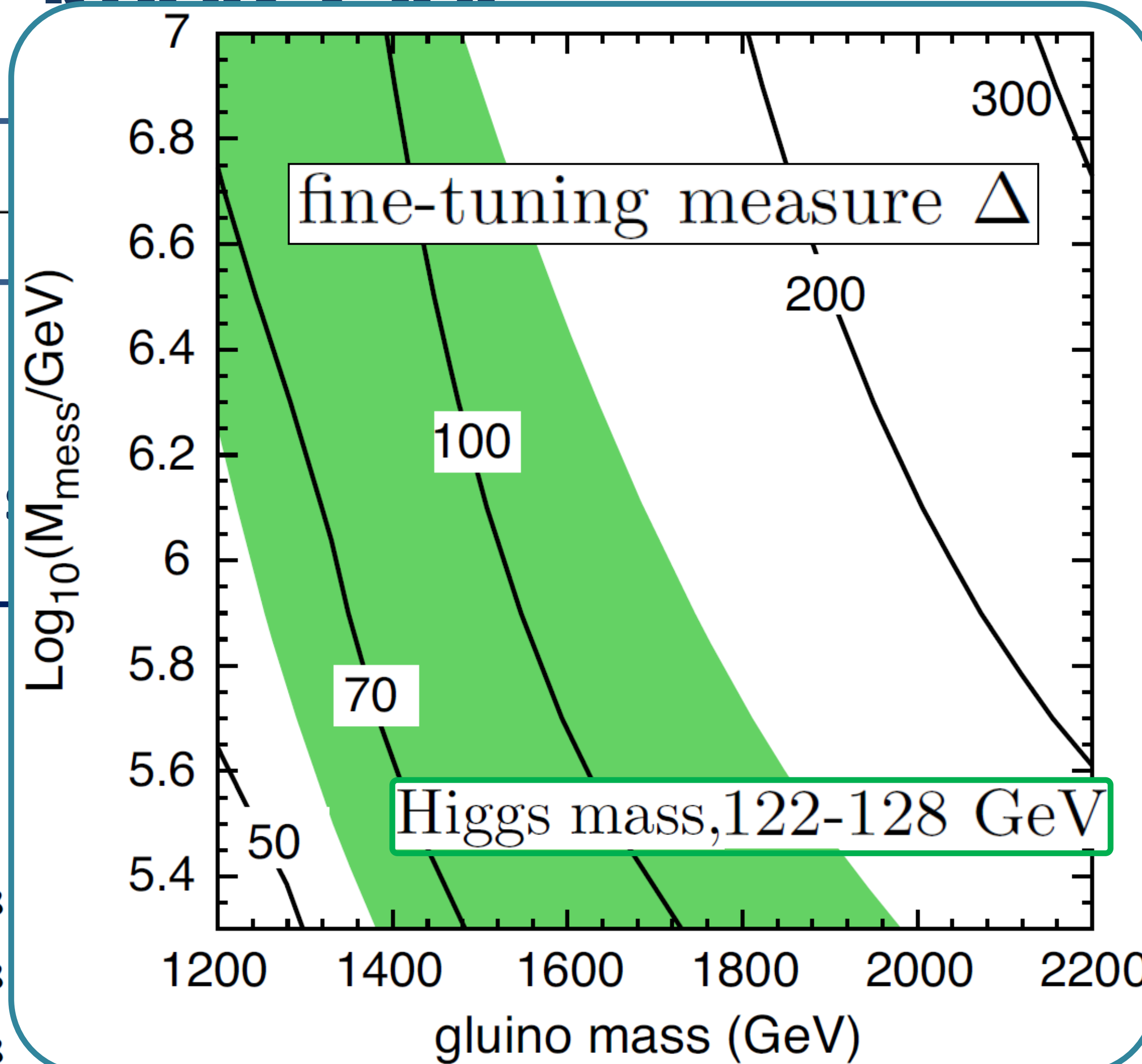


$\lambda_S = 1.0,\ \tan\beta = 4,\ \mu_{\rm eff} > 0,\ \mu' = 6\,{\rm TeV}$ and $N_5 = 2$

$$\mu_{\rm eff} \equiv \lambda_S v_S$$

Summary

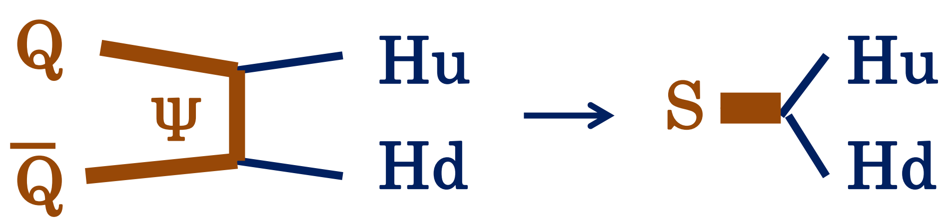
Summary

A **hidden meson** $\bar{S}$=QQ can be a singlet in NMSSM.

Usual dynamical SUSY breaking

Integrating out $\psi, \bar{\psi}$ → Confinement & Dynamical ~~SUSY~~

Additionally →



Higgs mass from SUSY ~~sector~~

	$SU(N)_H$	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
$Q_I\ (I=1,\cdots,N_f)$	$\mathbf{N}$	$\mathbf{1}$	$\mathbf{1}$	0
$\bar{Q}_I\ (I=1,\cdots,N_f)$	$\bar{\mathbf{N}}$	$\mathbf{1}$	$\mathbf{1}$	0
Φ_c	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$
$\bar{\Phi}_c$	$\mathbf{1}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$1/3$
Φ_l	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$1/2$
$\bar{\Phi}_l$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
f	$\mathbf{N}$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$
$\bar{f}$	$\bar{\mathbf{N}}$	$\bar{\mathbf{3}}$	$\mathbf{1}$	$1/3$
Ψ_u	$\mathbf{N}$	$\mathbf{1}$	$\mathbf{2}$	$1/2$
$\bar{\Psi}_d$	$\bar{\mathbf{N}}$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$X_m,\ Y_m$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	0

$$
\begin{aligned}
W = {} & \lambda_u H_u \bar{\Psi}_d Q_{N_f} + \lambda_d H_d \Psi_u \bar{Q}_{N_f} + \sum_I m_I Q_I \bar{Q}_I \\
& + \sum_{ij} \eta_{ij} X_m Q_i \bar{Q}_j + \sum_A \Big(\eta_c^A Y_m \Phi_c^A \bar{\Phi}_c^A + \eta_l^A Y_m \Phi_l^A \bar{\Phi}_l^A \\
& + M_c \Phi_c^A \bar{\Phi}_c^A + M_l \Phi_l^A \bar{\Phi}_l^A \Big) \\
& + m_\Psi \Psi_u \bar{\Psi}_d + m_f f \bar{f} + M_{XY} X_m Y_m + M_Y Y_m^2/2 \,,
\end{aligned}
$$

	Q_{N_f}	$\bar{Q}_{N_f}$	Q_p	$\bar{Q}_q$	X_1	X_2	X_3	X_m	Y_m	$(H_u\bar{\Psi}_d)$	$(H_d\Psi_u)$	$(\Phi_{l,c}\bar{\Phi}_{l,c})$
$U(1)$	$-4/5$	$-1/5$	$-1/5$	0	1	$4/5$	$2/5$	$1/5$	$-1/15$	$4/5$	$1/5$	$1/15$

	M_1	M_2	M_3	M_{XY}	m_{N_f}	m_p	M_Y	$M_{l,c}$
$U(1)$	-2	$-8/5$	$-4/5$	$-2/15$	1	$1/5$	$2/15$	$-1/15$

$$\frac{m_Z^2}{2} \approx -\mu_{\rm eff}^2 + \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1},$$

$$\sin 2\beta \approx \frac{2(\mu_{\rm eff}\mu' + \lambda_S \xi_F)}{m_{H_u}^2 + m_{H_d}^2 + 2\mu_{\rm eff}^2 + \lambda_S^2 v^2},$$

$$\mu_{\rm eff} \approx -\frac{\lambda_S \mu'}{2} \frac{2\xi_F - \lambda_S v^2 \sin 2\beta}{m_S^2 + \mu'^2 + \lambda_S^2 v^2},$$

$$\begin{pmatrix} h_1' \\ h_2' \\ h_3' \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} h_d \\ h_u \\ s_R \end{pmatrix}$$

$$\Delta = \max\left\{ \left| \frac{\partial \ln v}{\partial \ln |a|} \right| \right\}, \left(a \in \begin{array}{c} \text{fundamental mass} \\ \text{parameters} \end{array} \right)$$

where $a = \xi_F, \mu', \Lambda_{\rm mess}, |m_S^2|$ in our case. ($d\ln|\xi_F|$, $d\ln|\Lambda_{\rm mess}|$ and $d\ln|m_S^2|$ correspond to $d\ln|m_{N_f}|$, $d\ln|\bar{m}|$ and $d\ln|m_2|$, respectively.)