Higgs mixing in the NMSSM and light higgsinos

Yutaro SHOJI
Tohoku University, Japan
@LCWS14 in Belgrade

arXiv:1407.0955/hep-ph (submitted to JHEP)

Collaborators: Kwan Sik Jeong (IBS), Masahiro Yamaguchi

What if…

What if...

What if the Higgs potential is not fine-tuned?

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\underline{(2m_{\tilde{t}}^2 + |A_t|^2)}\ln\frac{\Lambda}{m_{\tilde{t}}} + \cdots$$

should not be so large

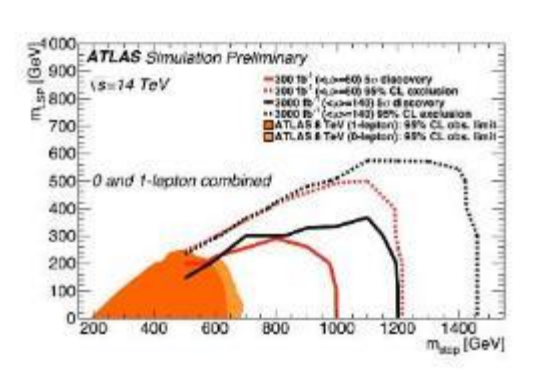
What if...

What if the Higgs potential is not fine-tuned?

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\underline{(2m_{\tilde{t}}^2 + |A_t|^2)}\ln\frac{\Lambda}{m_{\tilde{t}}} + \cdots$$

should not be so large

What if the stops are discovered at the next run of the LHC?



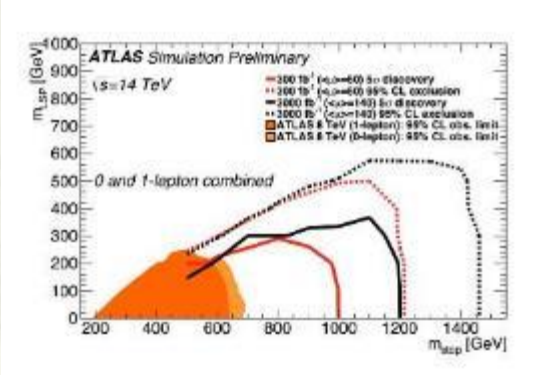
What if...

What if the Higgs potential is not fine-tuned?

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}\underline{(2m_{\tilde{t}}^2 + |A_t|^2)}\ln\frac{\Lambda}{m_{\tilde{t}}} + \cdots$$

should not be so large

What if the stops are discovered at the next run of the LHC?



What if the R-Parity is violated

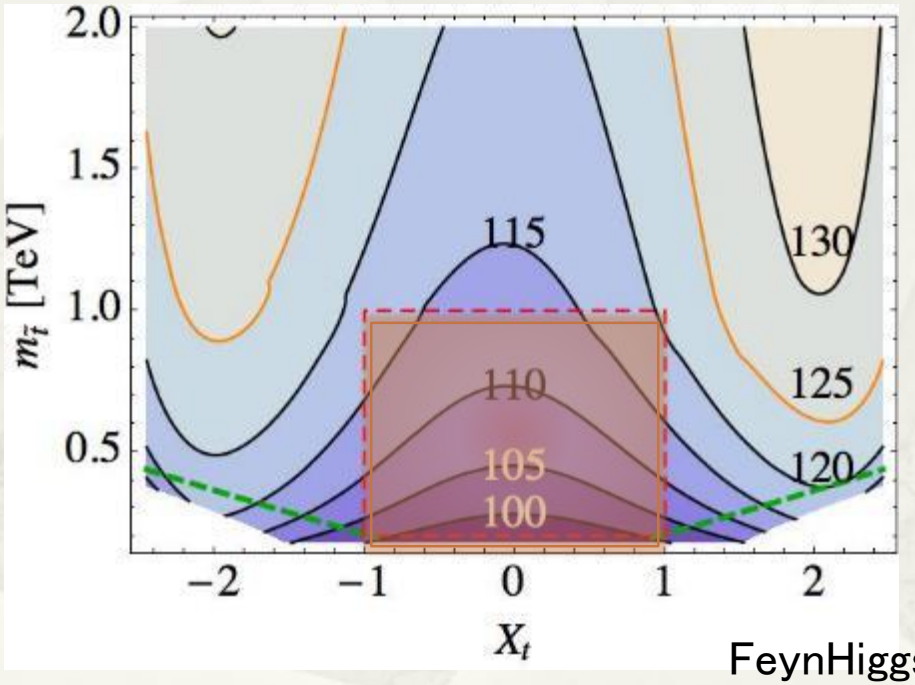
or the stops has a compressed spectrum with the LSP?

The Higgs mass tells us...

ATLAS: ~125.4GeV

CMS: ~125.0GeV

Higgs mass at large tan β in the MSSM



FeynHiggs 2.10.0

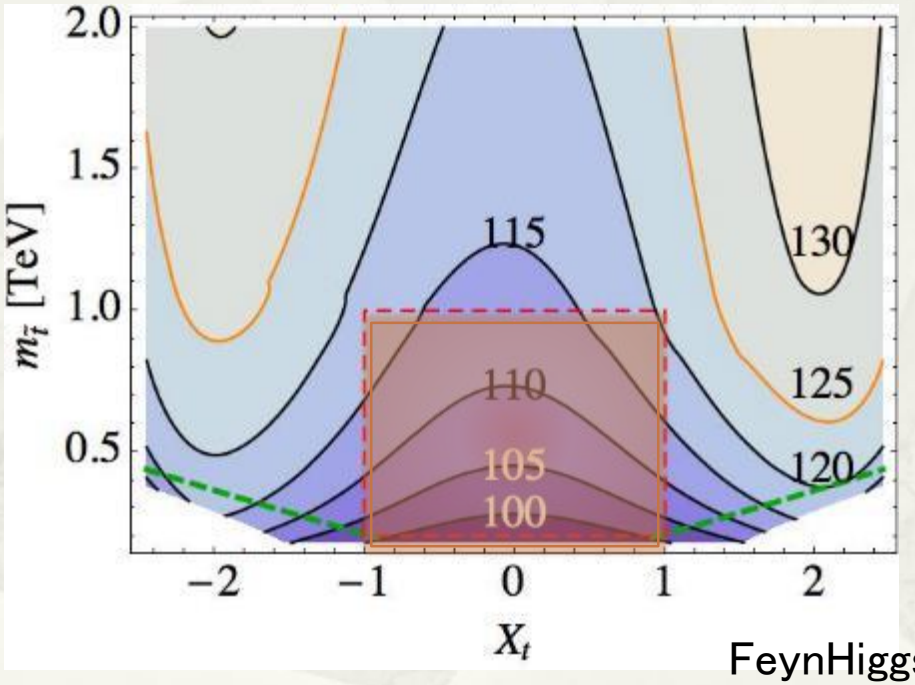
$$m_{\tilde{t}}^2 = \sqrt{m_{\tilde{t}_L}^2 m_{\tilde{t}_R}^2}$$

$$X_t = (A_t - \mu \cot\beta)/m_{\tilde{t}}$$

The Higgs mass tells us...

ATLAS: ~125.4GeV CMS: ~125.0GeV

Higgs mass at large tan β in the MSSM



FeynHiggs 2.10.0

$$m_{\tilde{t}} = 1\text{TeV}$$

$$\Rightarrow m_h \lesssim 120\text{GeV}$$

$$m_{\tilde{t}} = 600\text{GeV}$$

$$\Rightarrow m_h \lesssim 115\text{GeV}$$

$$m_{\tilde{t}}^2 = \sqrt{m_{\tilde{t}_L}^2 m_{\tilde{t}_R}^2}$$

$$X_t = (A_t - \mu \cot\beta)/m_{\tilde{t}}$$

<u>We need to go beyond the MSSM</u>

MSSM + Singlet

Z_3 invariant NMSSM, nMSSM, PQ-NMSSM,…

$$W = \lambda S H_u H_d + \cdots$$

MSSM + Singlet

Z_3 invariant NMSSM, nMSSM, PQ-NMSSM,…

$$W = \lambda S H_u H_d + \cdots$$

<u>F-term potential</u>

$$\Delta m_h^2 = (\lambda^2 v^2 - m_Z^2) \sin^2 2\beta$$

MSSM + Singlet

Z_3 invariant NMSSM, nMSSM, PQ-NMSSM,⋯

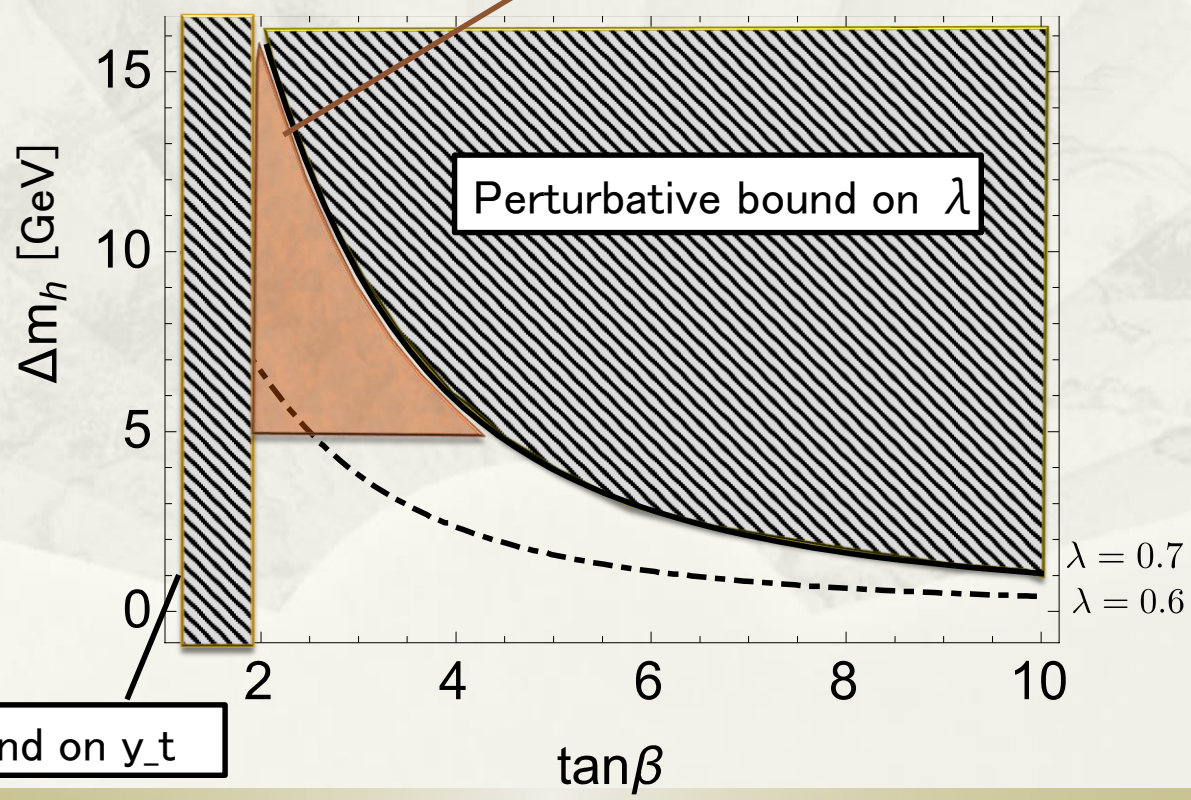
$$W = \lambda S H_u H_d + \cdots$$

F-term potential

$$\Delta m_h^2 = (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta$$

However,

Parameter region is limited



Perturbative bound on y_t

If the singlet boson is light,

$$\Delta m_h^2 \simeq (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta \boxed{+ (m_h^2 - m_s^2)\theta_{mix}^2}$$

$\tan\beta$ independent enhancement

Higgs mixing in the NMSSM

To carry out the analysis as model independently as possible, …

arbitrary (no CPV)

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

$$0.01 < \lambda < 1$$

Higgs mixing in the NMSSM

arbitrary (no CPV)

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

mass matrix

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

$\Lambda, m_{\hat{s}}^2, b$: model dependent parameters

$\mu = \lambda \langle S \rangle$

$\tan\beta = \langle Hu \rangle / \langle Hd \rangle$

Higgs mixing in the NMSSM

arbitrary (no CPV)

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

mass matrix

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Z boson mass + Q.C.

(H) $600\text{GeV} < m_{\tilde{t}} < 1\text{TeV}$

$\Rightarrow$ $105\text{GeV} < m_0 < 120\text{GeV}$

(L) $200\text{GeV} < m_{\tilde{t}} < 600\text{GeV}$

$\Rightarrow$ $100\text{GeV} < m_0 < 115\text{GeV}$

Higgs mixing in the NMSSM

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

$$\lambda\mu$$

Higgs mixing in the NMSSM

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

$\lambda\mu$

λ^2

Higgs mixing in the NMSSM

$$W = (\text{MSSM Yukawa}) + \lambda S H_u H_d + f(S)$$

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

$\lambda\mu$

λ^2

For each $\tan\beta$, the Higgsino mass can always be read off from the mass matrix.

The SM-like Higgs boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$h = \hat{h}\cos\theta_1 \cos\theta_2 - \hat{H}\sin\theta_1 - \hat{s}\cos\theta_1 \sin\theta_2$$

The SM-like Higgs boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

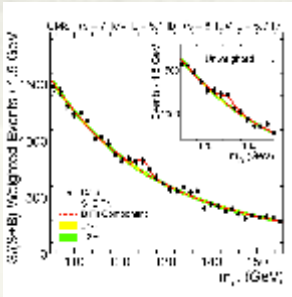
$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

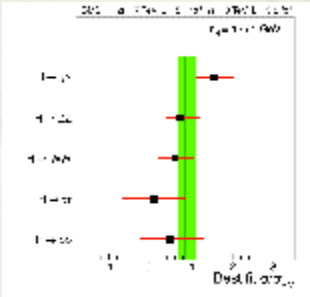
Diagonalize

$$h = \hat{h}\cos\theta_1 \cos\theta_2 - \hat{H}\sin\theta_1 - \hat{s}\cos\theta_1 \sin\theta_2$$

$$m_h \simeq 126\text{GeV}$$

$$h \simeq \hat{h}$$





The SM-like Higgs boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

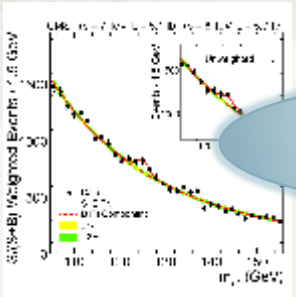
$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

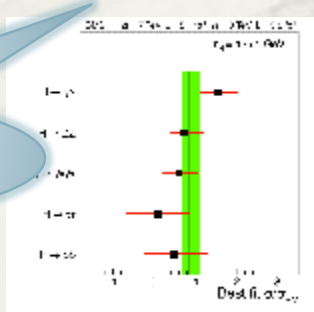
$$h = \hat{h}\cos\theta_1 \cos\theta_2 - \hat{H}\sin\theta_1 - \hat{s}\cos\theta_1 \sin\theta_2$$

$$m_h \simeq 126\mathrm{GeV}$$

$$h \simeq \hat{h}$$

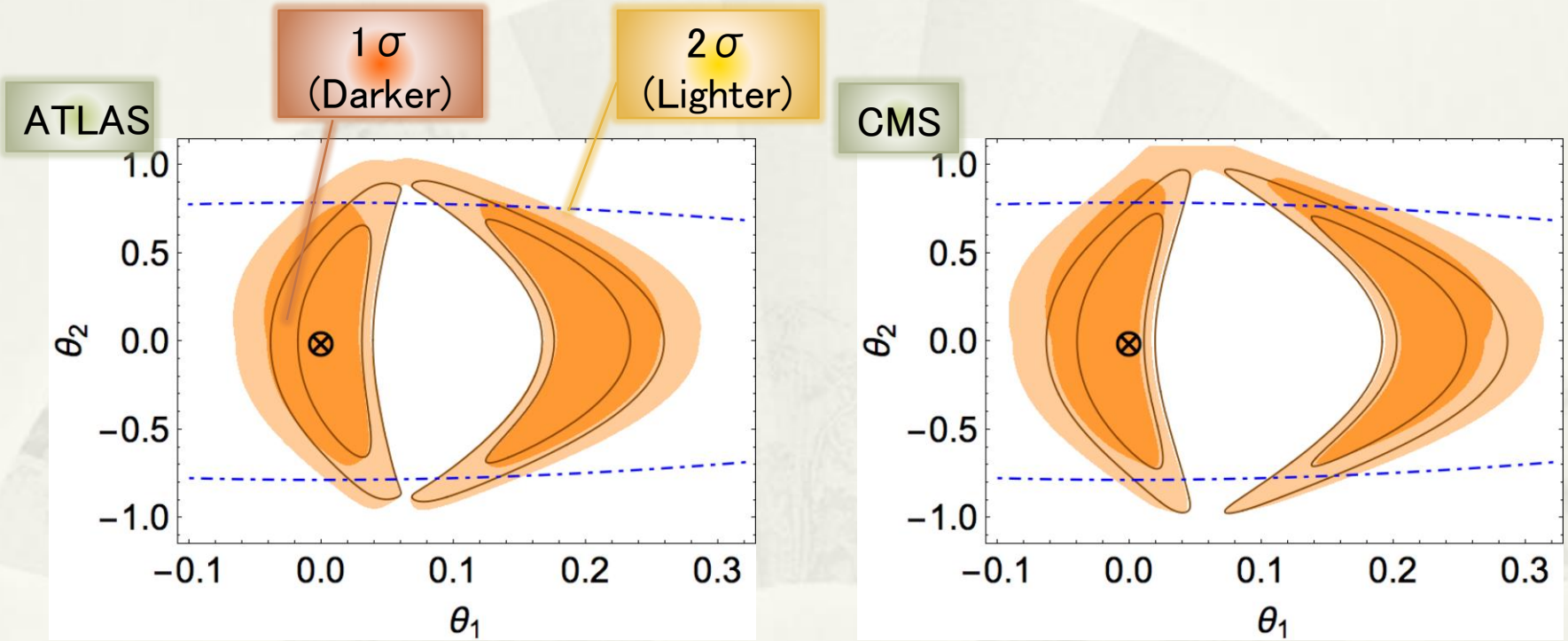


Let us quantify it.



Higgs signal strengths

χ^2 value on the (θ1, θ2) plane (bb, γγ, WW, ZZ and ττ channels are used.)



(Brown lines indicate 1 and 2 σ bands w/o SUSY loop contributions)

$$\tan\beta = 10$$

χ^2 is minimized with changing the parameters below

$$|X_t| < 1 \quad 200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV} \quad 100\mathrm{GeV} < |\mu| \quad \lambda < 1$$

The MSSM Higgs boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$H = \hat{h}(c_2 c_3 s_1 - s_2 s_3) + \hat{H} c_1 c_3 - \hat{s}(c_3 s_1 s_2 + c_2 s_3)$$

$$c_i = \cos\theta_i, \;\; s_i = \sin\theta_i$$

The MSSM Higgs boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$H = \hat{h}(c_2 c_3 s_1 - s_2 s_3) + \hat{H} c_1 c_3 - \hat{s}(c_3 s_1 s_2 + c_2 s_3)$$

$$c_i = \cos\theta_i, \;\; s_i = \sin\theta_i$$

$$350\mathrm{GeV} \lesssim m_H \lesssim 1\mathrm{TeV}$$

b->s γ

The Higgs sector should not be fine-tuned

Let us take

$$m_H = 800\mathrm{GeV}$$

The singlet-like boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \\ \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$s = \hat{h}(c_3 s_2 + c_2 s_1 s_3) + \hat{H} c_1 s_3 + \hat{s}(c_2 c_3 - s_1 s_2 s_3)$$

The singlet-like boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \end{array}$$

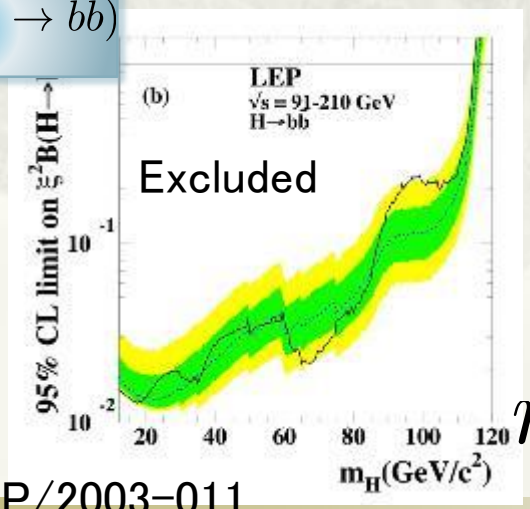
$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$s = \hat{h}(c_3 s_2 + c_2 s_1 s_3) + \hat{H} c_1 s_3 + \hat{s}(c_2 c_3 - s_1 s_2 s_3)$$

$$\frac{\sigma_h}{\sigma_h^{\rm SM}} {\rm Br}(\cancel{h} \to bb)$$

S



m_s [GeV]

CERN-EP/2003-011

The singlet-like boson

$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \end{array}$$

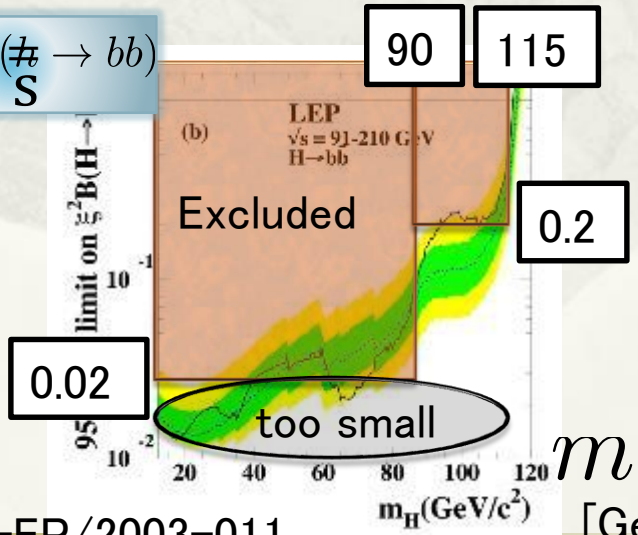
$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$s = \hat{h}(c_3 s_2 + c_2 s_1 s_3) + \hat{H} c_1 s_3 + \hat{s}(c_2 c_3 - s_1 s_2 s_3)$$

$$\frac{\sigma_h}{\sigma_h^{\rm SM}} {\rm Br}(\cancel{h} \to bb)$$

S



m_s [GeV]

CERN-EP/2003-011

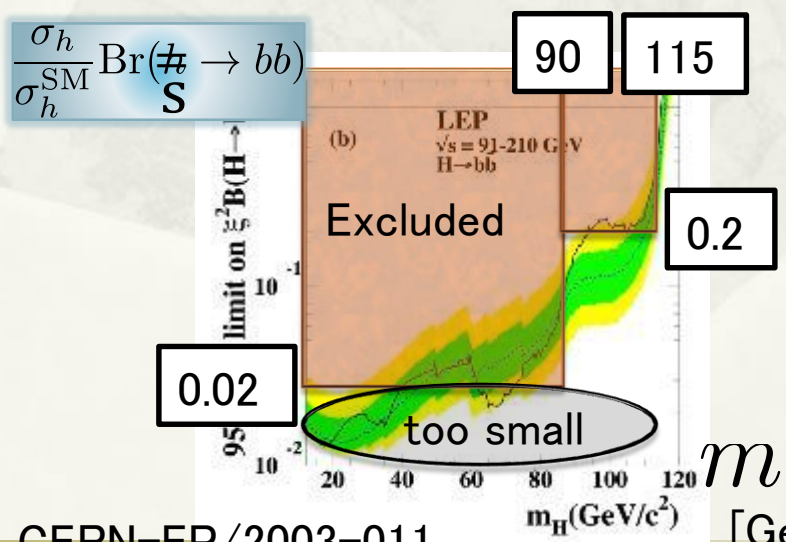
The singlet-like boson

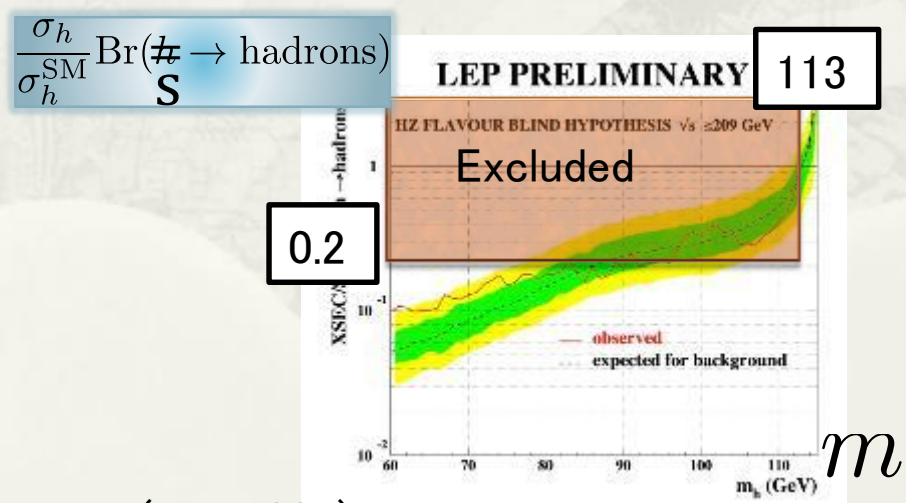
$$\begin{array}{ccc} \hat{h} & \hat{H} & \hat{s} \end{array}$$

$$\begin{pmatrix} m_0^2 + (\lambda^2 v^2 - m_Z^2)\sin^2 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ -(\lambda^2 v^2 - m_Z^2)\sin 2\beta \cos 2\beta & -(\lambda^2 v^2 - m_Z^2)\sin^2 2\beta + \frac{2b}{\sin 2\beta} & \lambda v \Lambda \cos 2\beta \\ \lambda v(2\mu - \Lambda \sin 2\beta) & \lambda v \Lambda \cos 2\beta & m_{\hat{s}}^2 \end{pmatrix}$$

Diagonalize

$$s = \hat{h}(c_3 s_2 + c_2 s_1 s_3) + \hat{H} c_1 s_3 + \hat{s}(c_2 c_3 - s_1 s_2 s_3)$$





m_s [GeV]

CERN-EP/2003-011

PoS(HEP2005)328

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

$m_0 \lesssim 120\mathrm{GeV}$ $m_s \gtrsim 90\mathrm{GeV}$

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2 - m_0^2) - (\theta_1^2+\theta_2^2)(m_h^2 - m_s^2)\right]$$

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

$m_0 \lesssim 120\mathrm{GeV}$

$m_s \gtrsim 90\mathrm{GeV}$

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2 - m_0^2) - (\theta_1^2+\theta_2^2)(m_h^2 - m_s^2)\right]$$

Can be bounded below!

Upper bound on μ

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

$m_0 \lesssim 120\mathrm{GeV}$ $\qquad$ $m_s \gtrsim 90\mathrm{GeV}$

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2 - m_0^2) - (\theta_1^2+\theta_2^2)(m_h^2 - m_s^2)\right]$$

If $\theta_1^2 + \theta_2^2 \lesssim 0.19$

$$\lambda > \frac{m_Z}{v} \cong 0.52$$

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

$m_0 \lesssim 120\mathrm{GeV}$ $\qquad$ $m_s \gtrsim 90\mathrm{GeV}$

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2 - m_0^2) - (\theta_1^2+\theta_2^2)(m_h^2 - m_s^2)\right]$$

If $\theta_1^2 + \theta_2^2 \lesssim 0.19$

$\lambda > \frac{m_Z}{v} \cong 0.52$ $\Rightarrow$ $|\mu| \lesssim 350\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$

Higgsino mass –approx.-

For large m_H,

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

$m_0 \lesssim 120\mathrm{GeV}$ $\quad$ $m_s \gtrsim 90\mathrm{GeV}$

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2 - m_0^2) - (\theta_1^2+\theta_2^2)(m_h^2 - m_s^2)\right]$$

If $\theta_1^2 + \theta_2^2 \lesssim 0.19$

$$\lambda \lesssim \frac{m_Z}{v} \simeq 0.52$$

$$|\mu| \lesssim 350\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

Chargino search

LC

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2\mathrm{GeV}$$

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2\mathrm{GeV}$$

(=>Anyway, we don't need mixings…)

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2\mathrm{GeV}$$

(=>Anyway, we don't need mixings…)

B. Suppressed s->bb

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2\mathrm{GeV}$$

(=>Anyway, we don't need mixings…)

LC

B. Suppressed s->bb

Light boson searches

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2 \mathrm{GeV}$$

(=>Anyway, we don't need mixings…)

LC

B. Suppressed s->bb

Light boson searches

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

C. large mixing angles + large tan β

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

A few exceptions

The higgsinos tend to be light but there are a few exceptions.

A. small tan β (e.g. less than 3)

$$|\lambda\mu| \simeq \frac{m_H^2}{2v\tan\beta}\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2} \lesssim 185\left(\frac{10}{\tan\beta}\right)\left(\frac{m_H}{800\mathrm{GeV}}\right)^2\mathrm{GeV}$$

(=>Anyway, we don't need mixings…)

LC

B. Suppressed s->bb

Light boson searches

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

LC, LHC

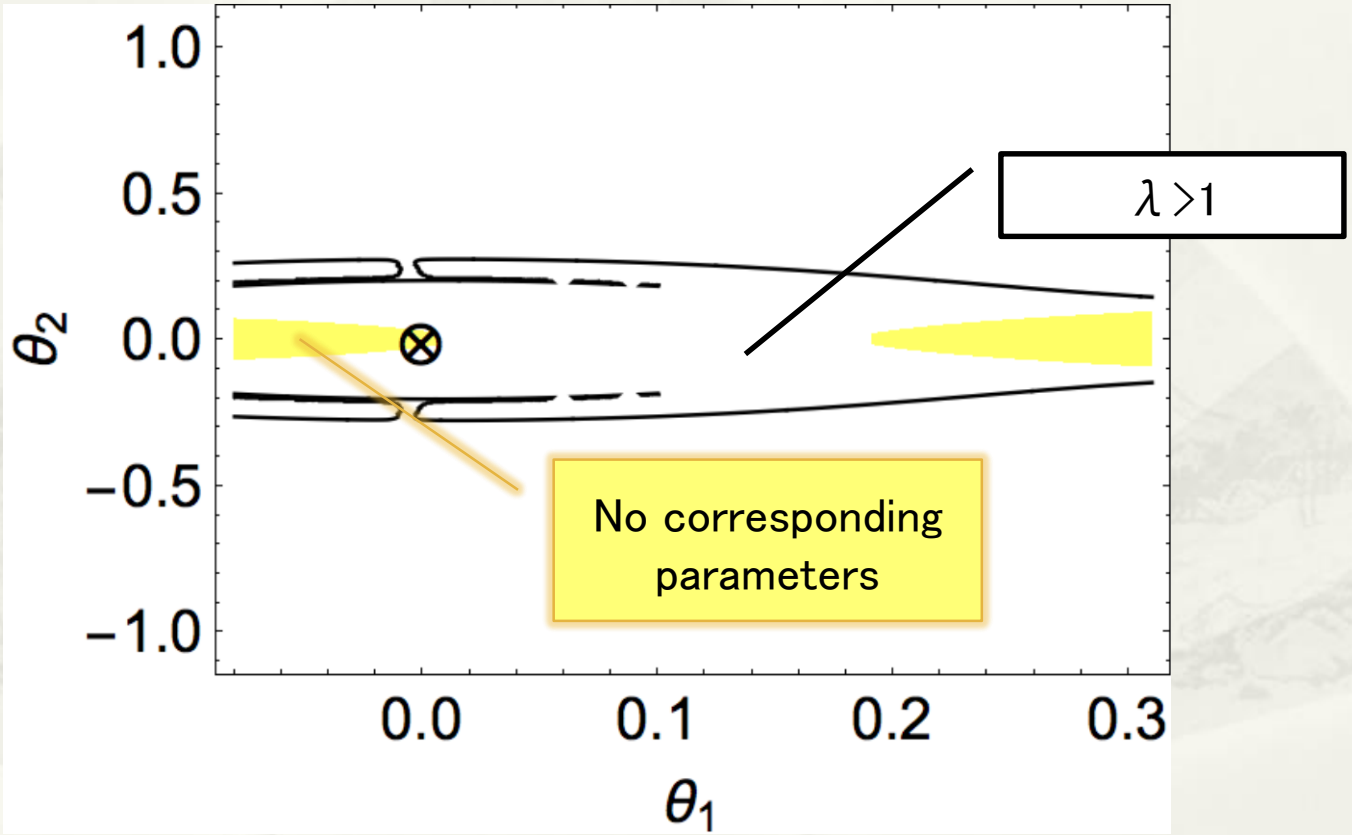
C. large mixing angles + large tan β

Higgs coupling measurement

$$\lambda^2 \simeq \frac{m_Z^2}{v^2} + \frac{\tan^2\beta}{4v^2}\left[(m_h^2-m_0^2)-(\theta_1^2+\theta_2^2)(m_h^2-m_s^2)\right]$$

Numerical result (tanβ=10)

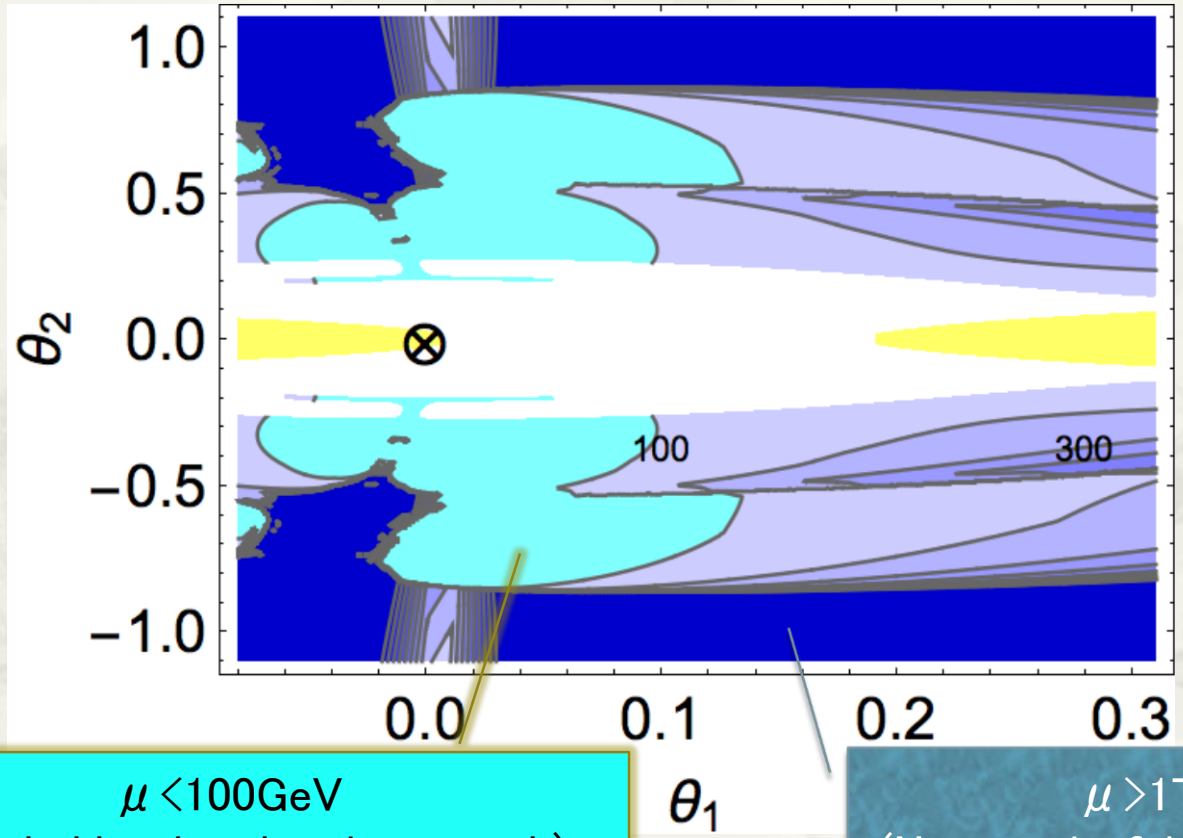
Available parameter region



(H) $200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV}$

Numerical result (tanβ=10)

Upper bound on μ



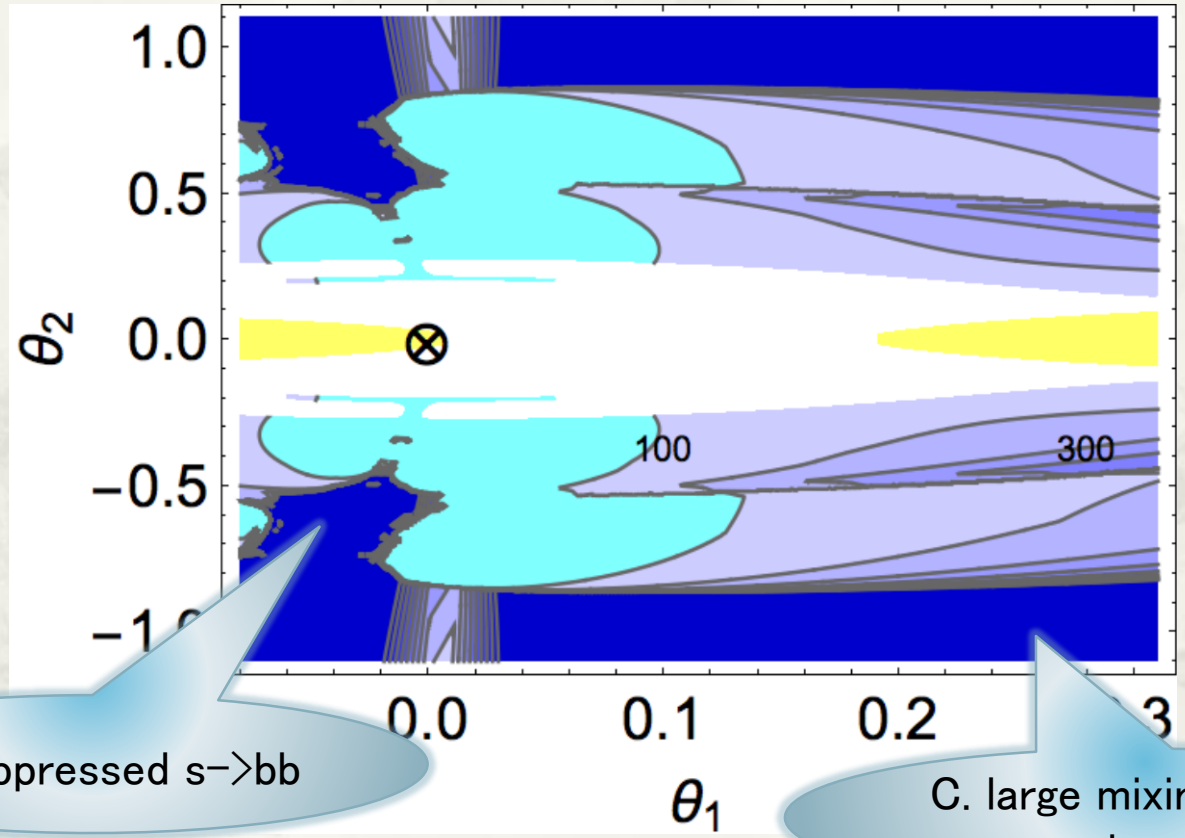
μ <100GeV
(Excluded by the chargino search)

μ >1TeV
(No meaningful upper bound)

(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$

Numerical result (tanβ=10)

Upper bound on μ



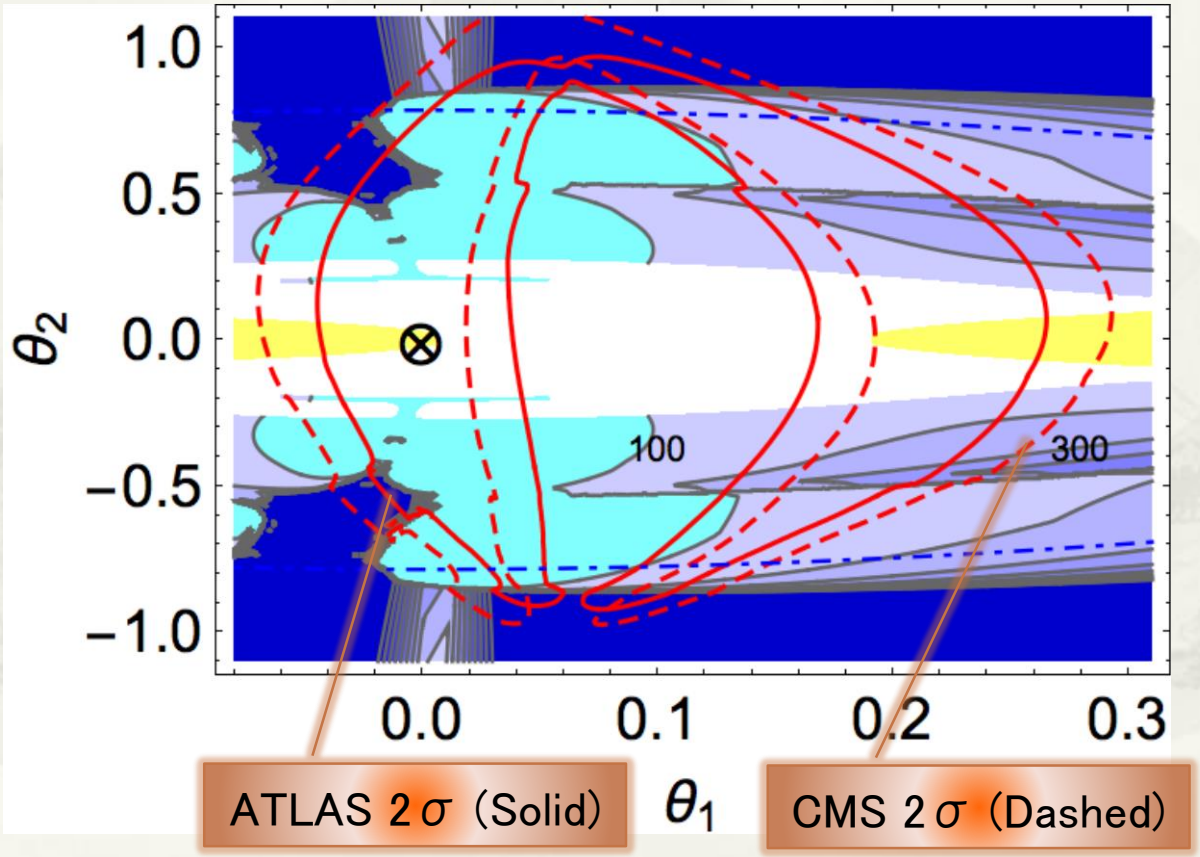
B. Suppressed s->bb

C. large mixing angles and tan β

(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$

Numerical result (tanβ=10)

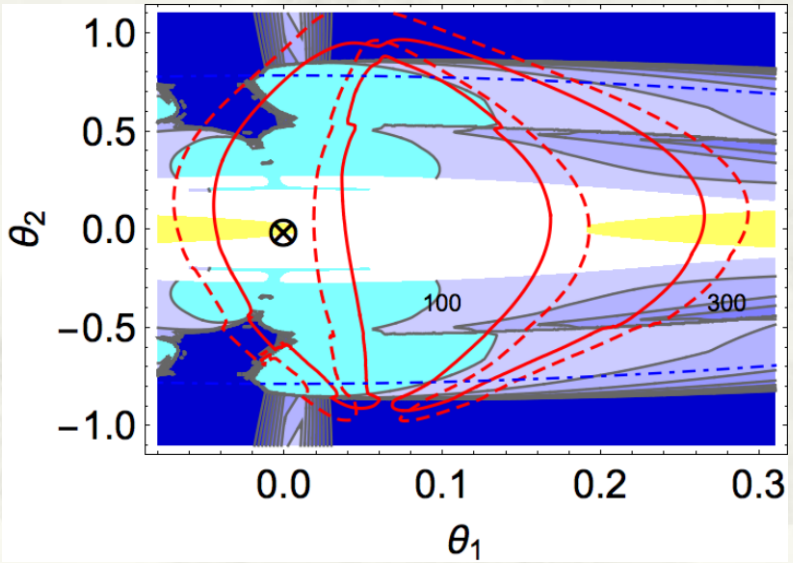
Higgs signal strengths



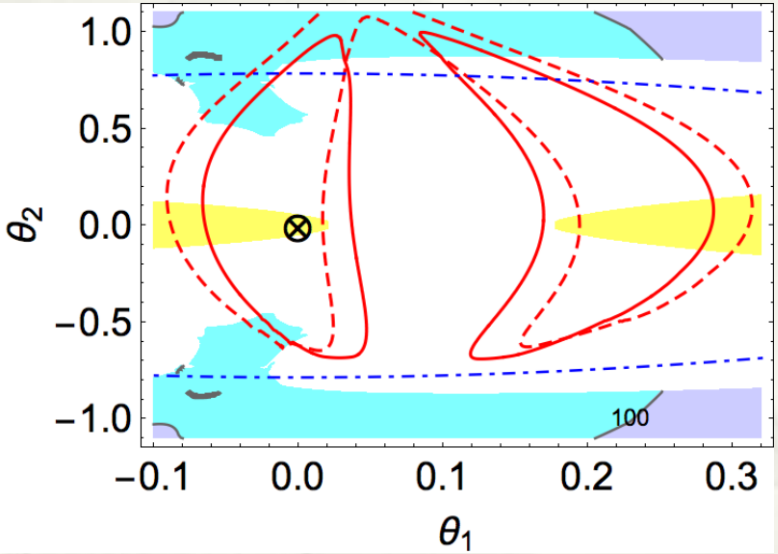
(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$

Numerical result (tanβ=10)

(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$

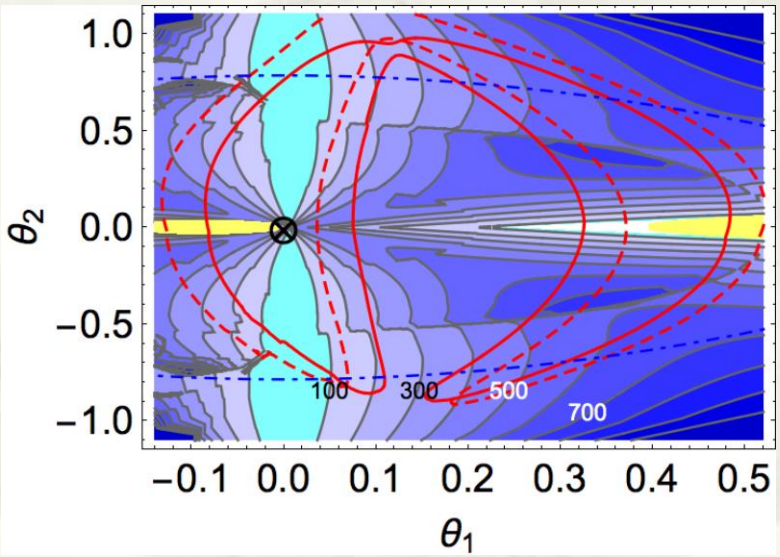


(L) $200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV}$

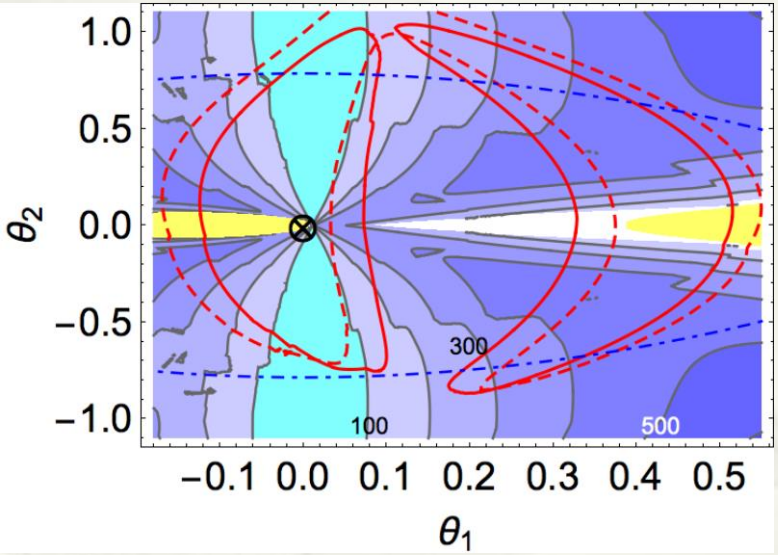


Numerical result (tanβ=5)

(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$



(L) $200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV}$



Summary

The NMSSM can accommodate 126GeV Higgs mass with sub-TeV SUSY.

Summary

The NMSSM can accommodate 126GeV Higgs mass with sub-TeV SUSY.

F-term + Higgs mixing

Summary

The NMSSM can accommodate 126GeV Higgs mass with sub-TeV SUSY.

F-term + Higgs mixing

Light singlet-like state

➡ A Singlet-like boson can be discovered

Large mixing angle

➡ The Higgs signal strengths can deviate

Summary

The NMSSM can accommodate 126GeV Higgs mass with sub-TeV SUSY.

F-term + Higgs mixing

Light singlet-like state

➡ A Singlet-like boson can be discovered

Large mixing angle

➡ The Higgs signal strengths can deviate

That's not all!

The higgsinos will be very light

Summary

The NMSSM can accommodate 126GeV Higgs mass with sub-TeV SUSY.

The stops can be light — LHC, LC

F-term + Higgs mixing

Light singlet-like state

A Singlet-like boson can be discovered — LC

Large mixing angle

The Higgs signal strengths can deviate — LHC, LC

That's not all!

The higgsinos will be very light — LC

BACKUPS

Analysis
- the Higgs signal streangths -

To get the preferred region in θ plane, let us assume

- ・No systematic errors
- ・Independent Gaussian distributions
  [Two linear combinations of $\gamma\gamma$ channels (ggF and VBF/VH) are used]

	WW/ggF	ZZ/ggF	bb/VH-VBF	$\tau\tau$/VH-VBF	$\gamma\gamma$/X	$\gamma\gamma$/Y
ATLAS	0.99 ± 0.30	1.43 ± 0.38	1.09 ± 0.34		1.49 ± 0.36	0.61 ± 0.75
CMS	0.68 ± 0.20	0.92 ± 0.28	1.15 ± 0.62	1.10 ± 0.41	1.42 ± 0.31	0.89 ± 0.61

$$\mu^X - 1 = (\mu^{ggF} - 1)\cos\varphi + (\mu^{VH/VBF} - 1)\sin\varphi$$
$$\mu^Y - 1 = -(\mu^{ggF} - 1)\sin\varphi + (\mu^{VH/VBF} - 1)\cos\varphi$$

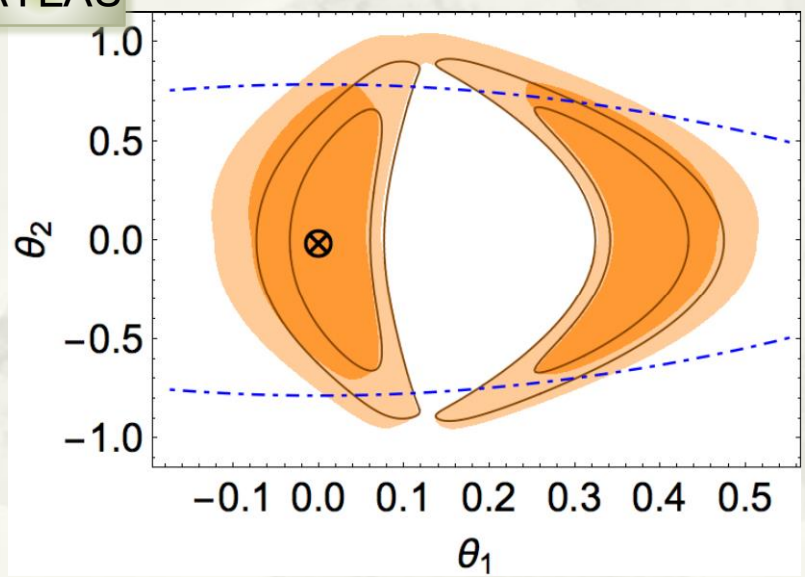
$$\cos\varphi = 0.98(\mathrm{ATLAS}), 0.97(\mathrm{CMS})$$

hep-ex/1307.1427, ATLAS-CONF-2014-009, CMS-PAS-HIG-13-005,
hep-ex/1408.7084, hep-ex1407.0558

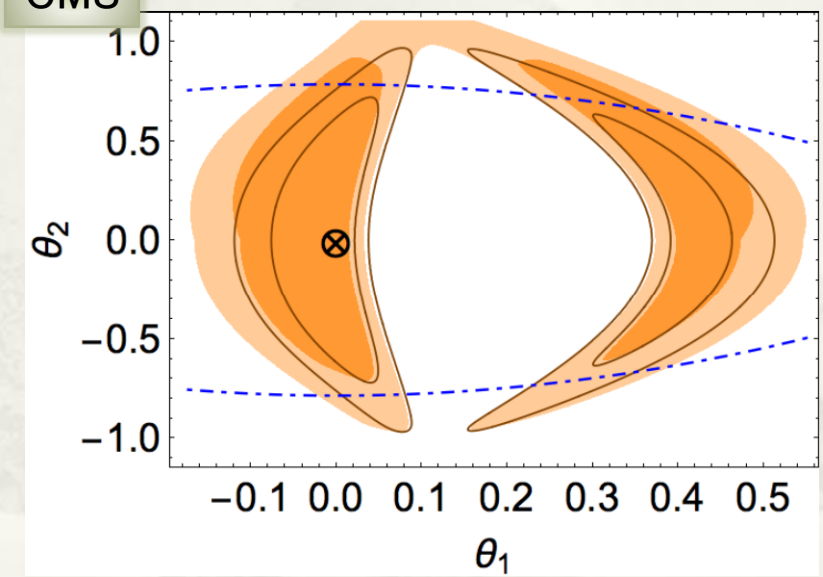
Higgs signal strengths

Tan β =5

ATLAS



CMS



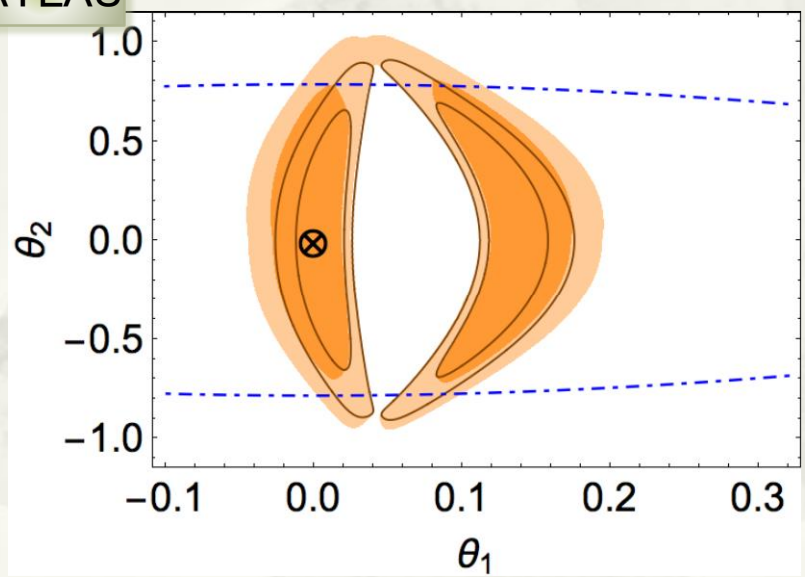
χ ^2 is minimized with changing the parameters below

$$|X_t| < 1 \quad 200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV} \quad 100\mathrm{GeV} < |\mu| \quad \lambda < 1$$

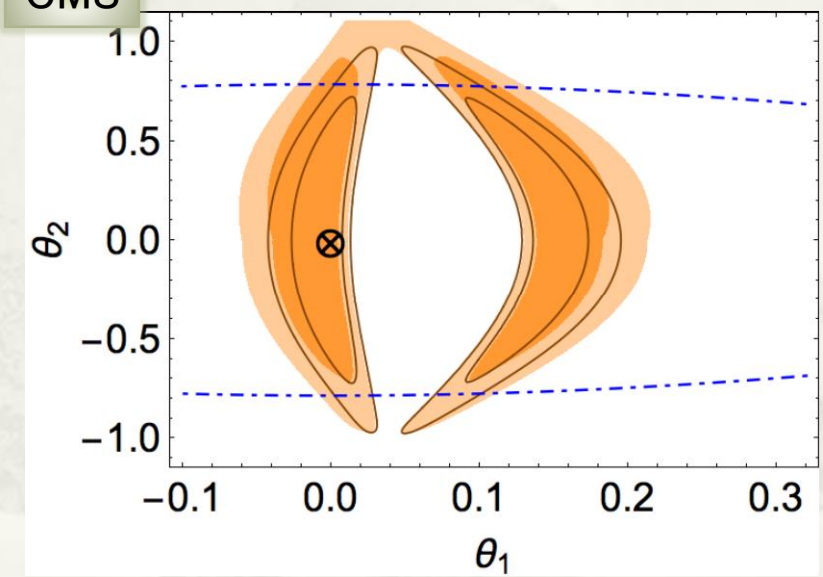
Higgs signal strengths

Tan β =15

ATLAS



CMS

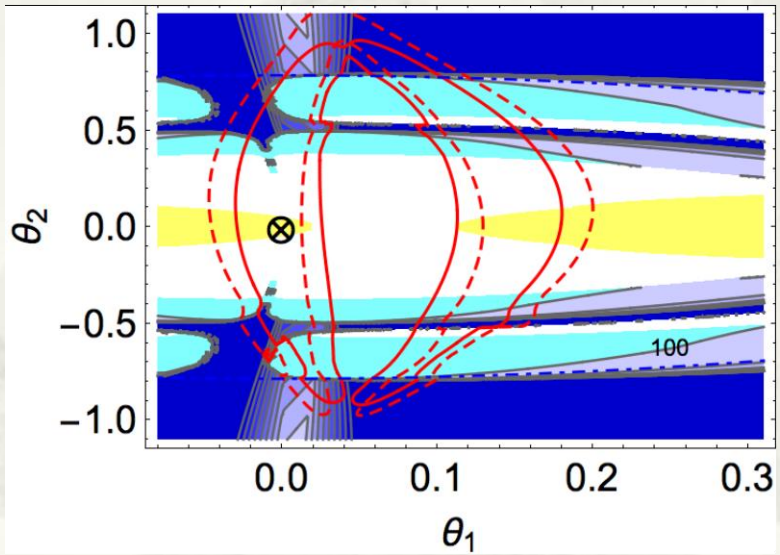


χ ^2 is minimized with changing the parameters below

$$|X_t| < 1 \quad 200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV} \quad 100\mathrm{GeV} < |\mu| \quad \lambda < 1$$

Numerical result (tanβ=15)

(H) $600\mathrm{GeV} < m_{\tilde{t}} < 1\mathrm{TeV}$



(L) $200\mathrm{GeV} < m_{\tilde{t}} < 600\mathrm{GeV}$