一般的なNMSSMにおける Higgs混合と軽いHiggsino

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Collaborators: Kwang Sik Jeong (DESY), Masahiro Yamaguchi
=> IBS from Oct.

arXiv: 1407.0955

Where is SUSY?

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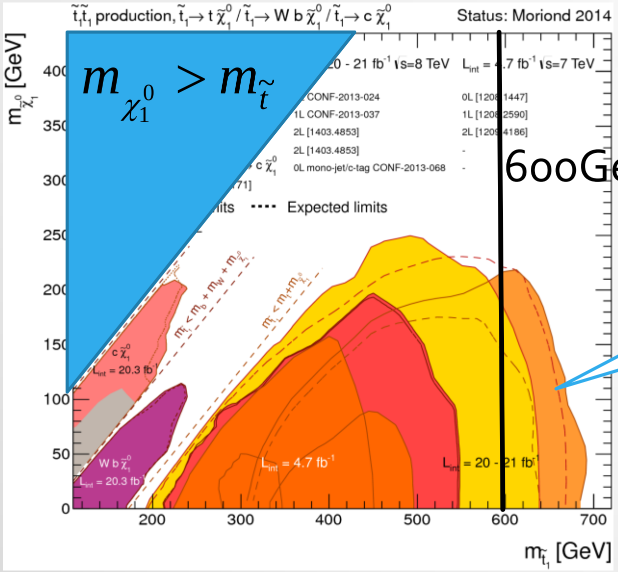

Stops have not been discovered yet.

ATLAS, Moriond2014

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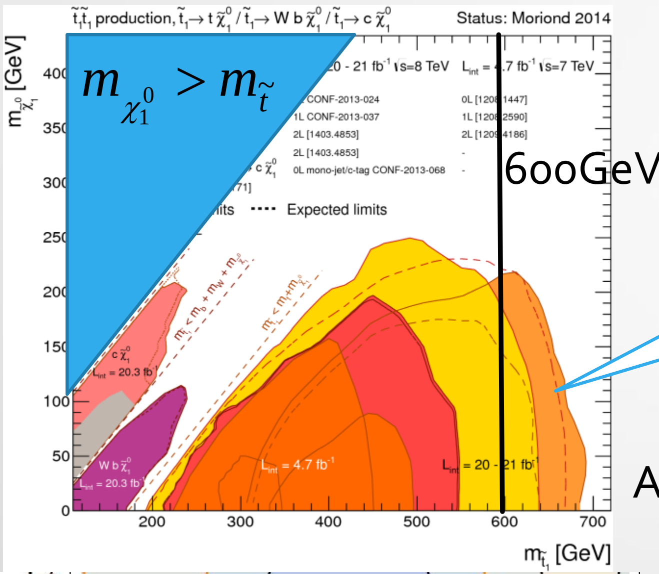

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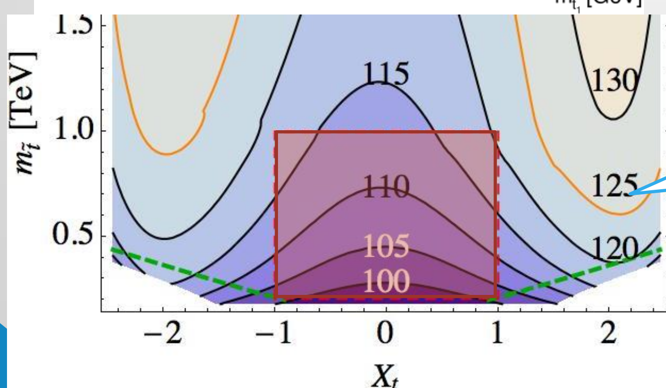

FeynHiggs 2.10.0

The Higgs boson mass requires heavy stop masses in the MSSM.

$$m_{\tilde{t}}^2 = \sqrt{m_{t_R}^2 m_{t_L}^2}$$

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

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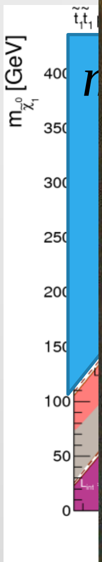

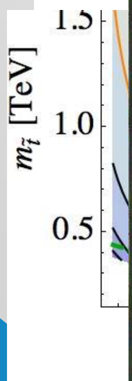

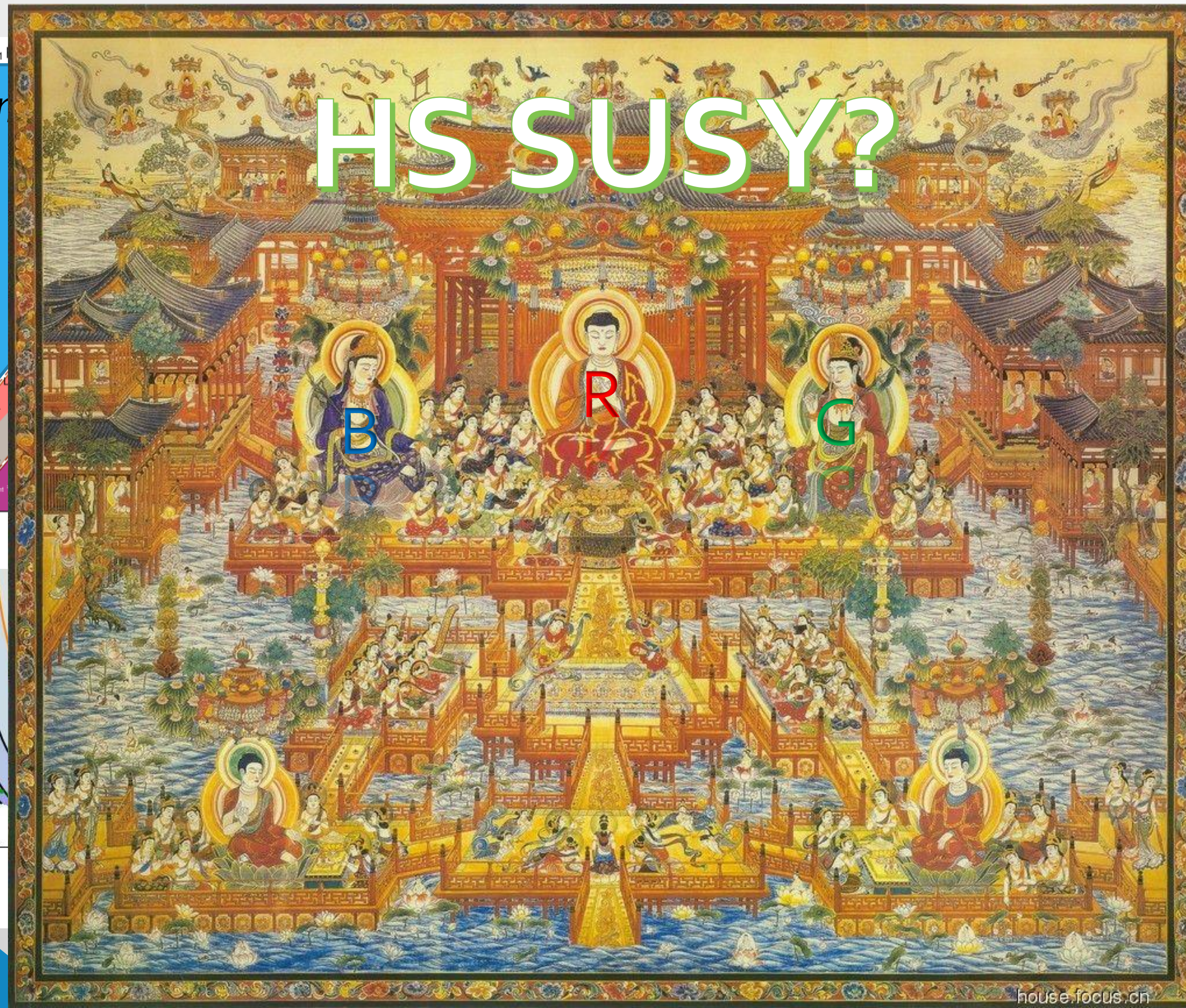

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$^2_{t_L}$

$\cot\beta) / m_{\tilde{t}}$

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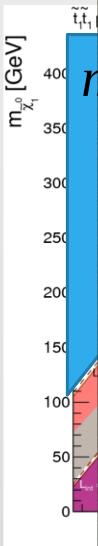

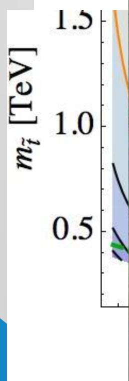

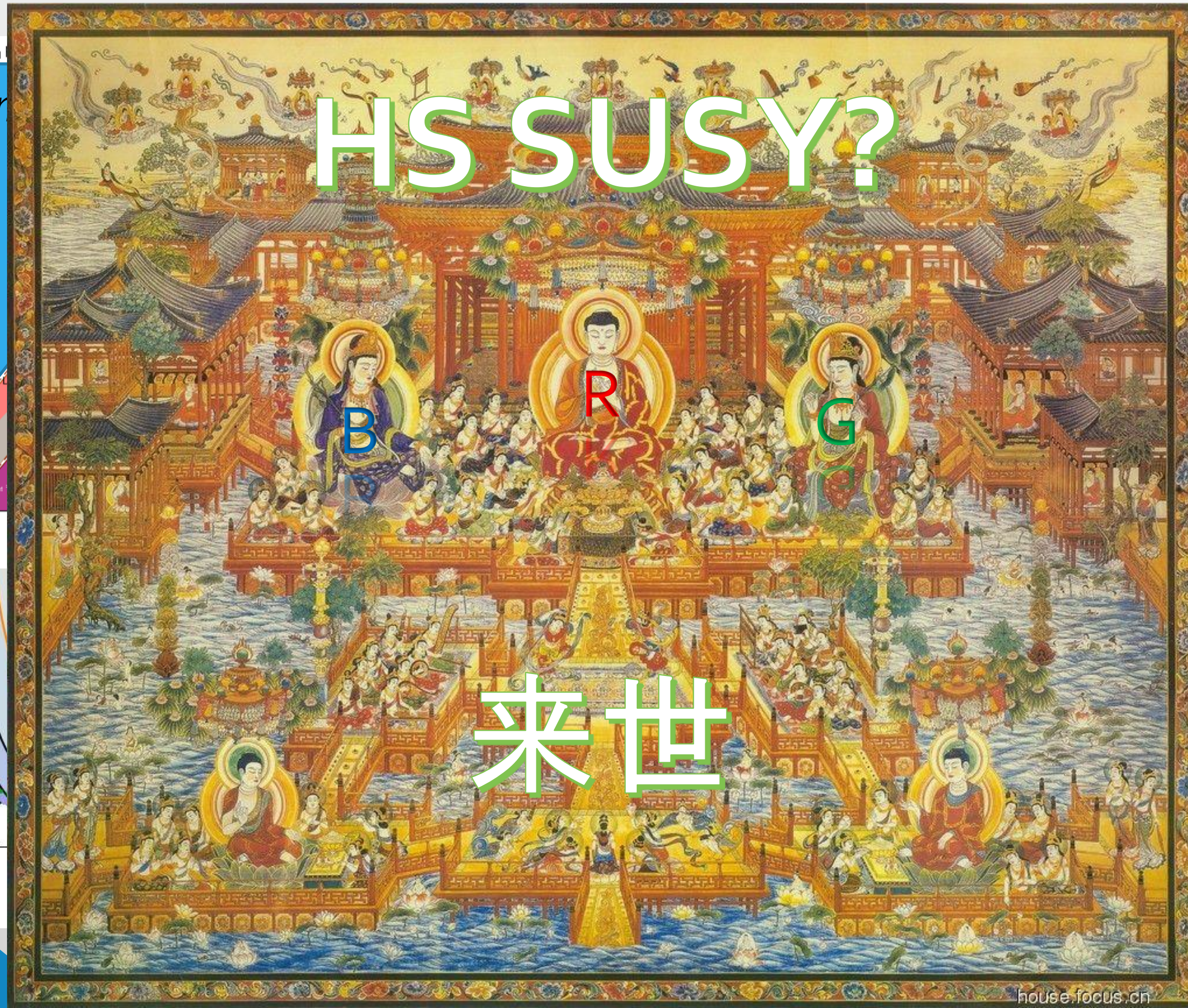

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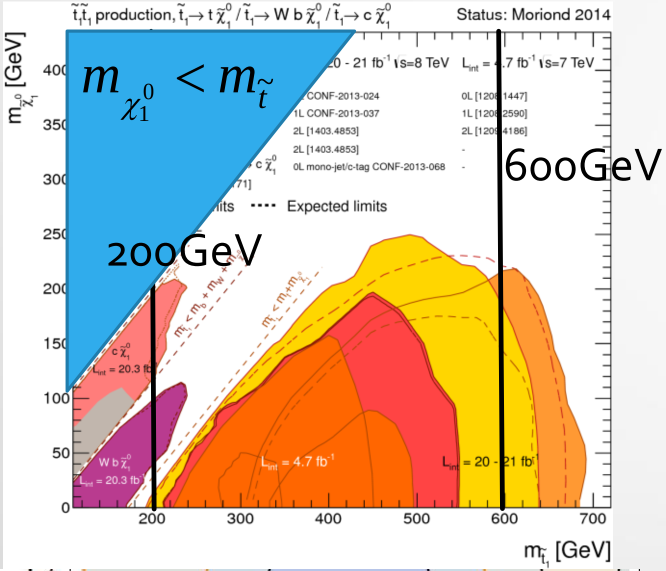
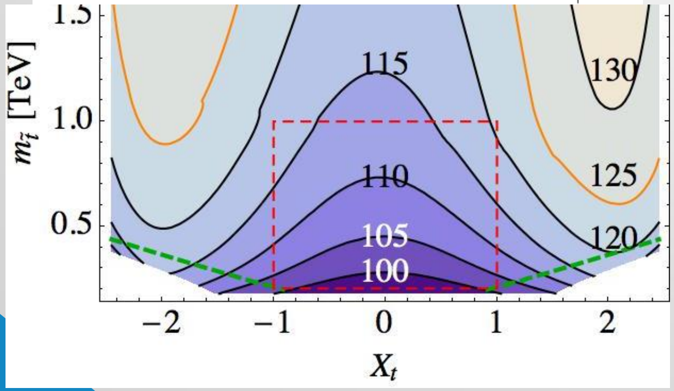
But, don’t worry!

Maybe, “she” is just around the corner!





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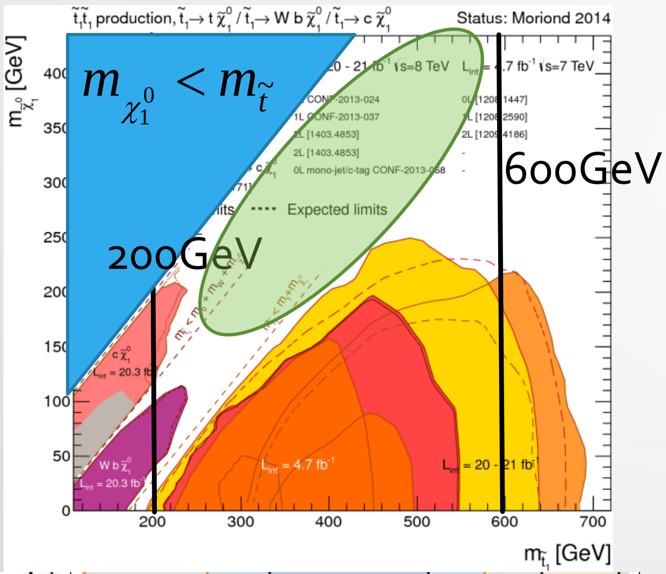

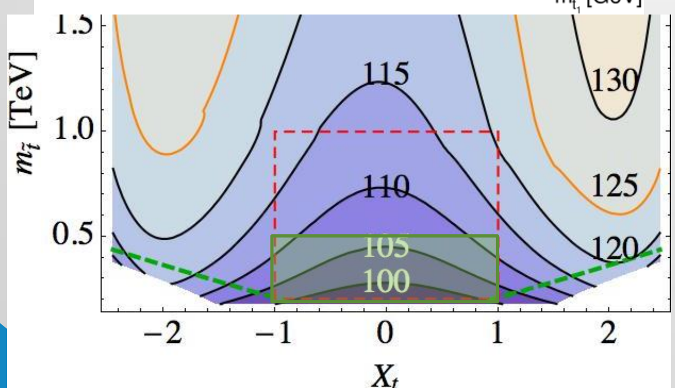

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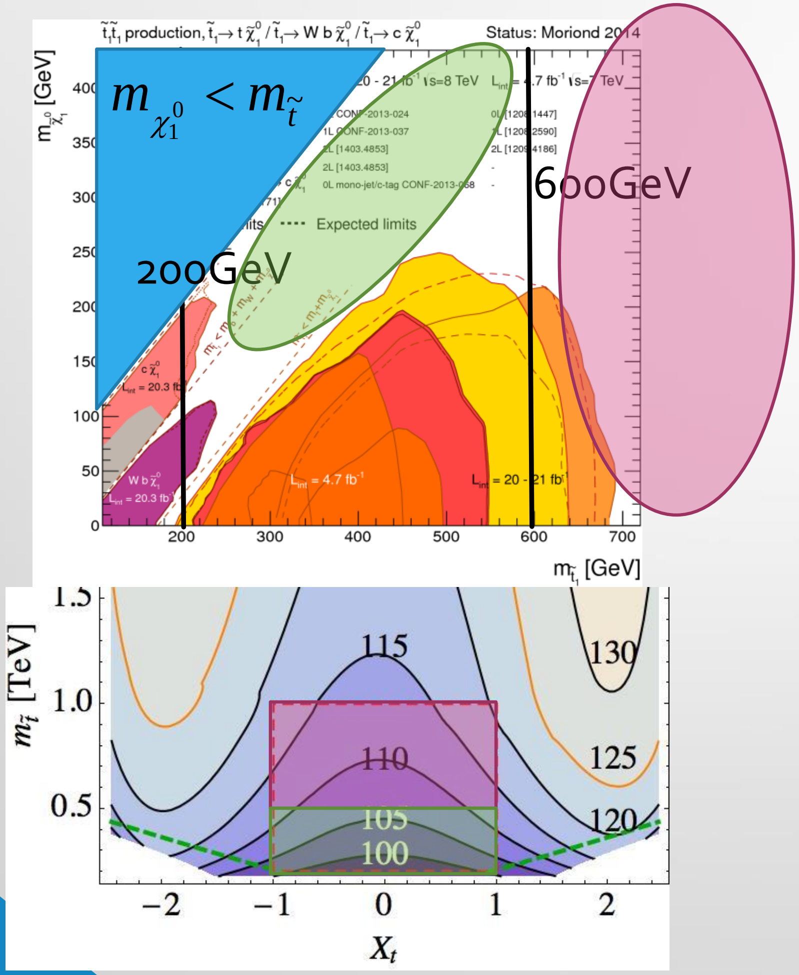

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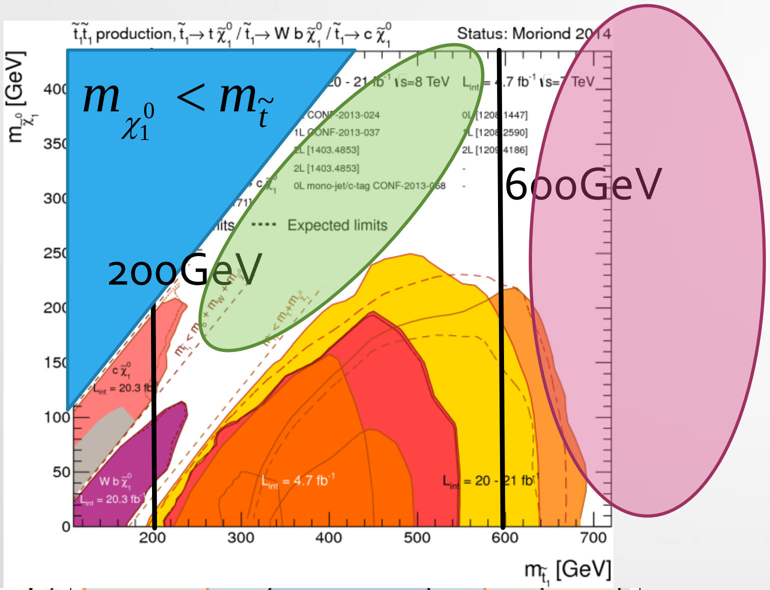

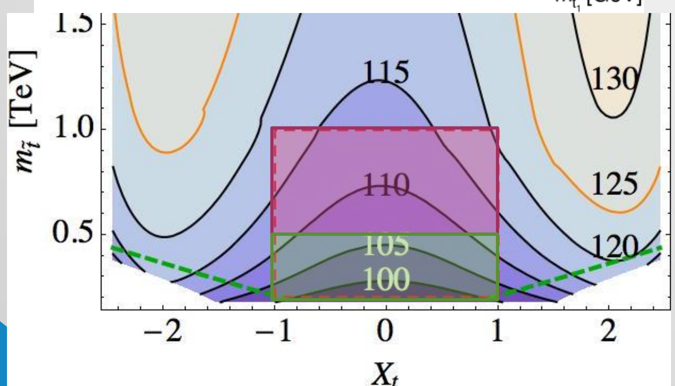

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We **need additional** contributions to the Higgs mass.

How can we gain the Higgs mass?

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Add a SM gauge singlet supermultiplet!

Z_3-invariant NMSSM, nMSSM, PQ-NMSSM, U(1)-extended MSSM, …

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F-term potential of S

But it can be sizable only when

$$2 < \tan\beta < 4$$

(perturbative bounds)

$$\tan\beta = \langle H_u^0 \rangle / \langle H_d^0 \rangle$$

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With a light singlet boson

Mixing with a singlet

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$$m_S < m_h = 126\text{GeV}$$

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- The **Higgs signal strength** can **deviate** from the SM value.
- But, it is still **alive**.

(perturbative bounds)

With a light singlet boson

Mixing with a singlet

In order to push up the Higgs mass, we need

$$m_S < m_h = 126\mathrm{GeV}$$

What would be the outcome of the Higgs results?

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

observed

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MSSM Higgs

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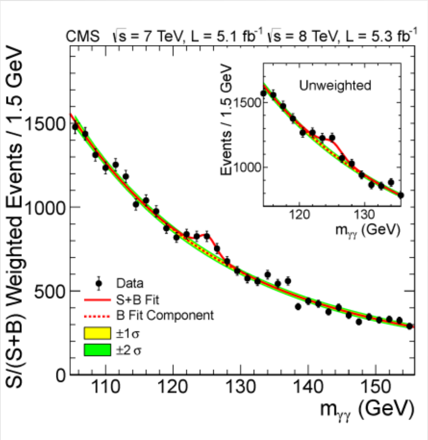
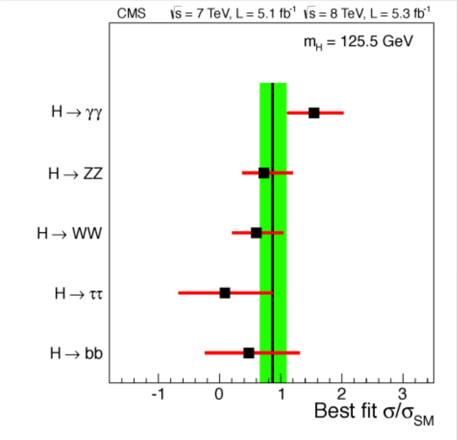
$$m_h = 126\text{GeV}$$



$$h \approx \hat{h}$$



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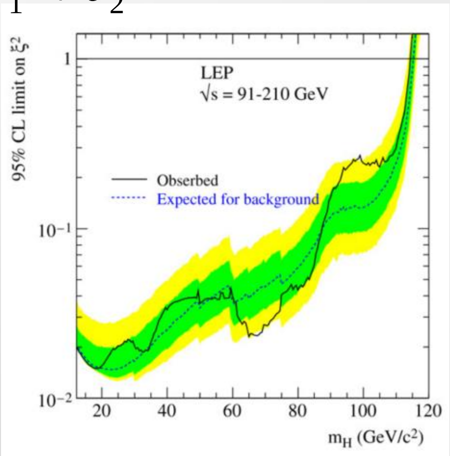
The LEP Higgs search

$\theta_1^2 + \theta_2^2$



m_S [GeV]

CERN-EP/2003-011

What would be the outcome of the Higgs results?

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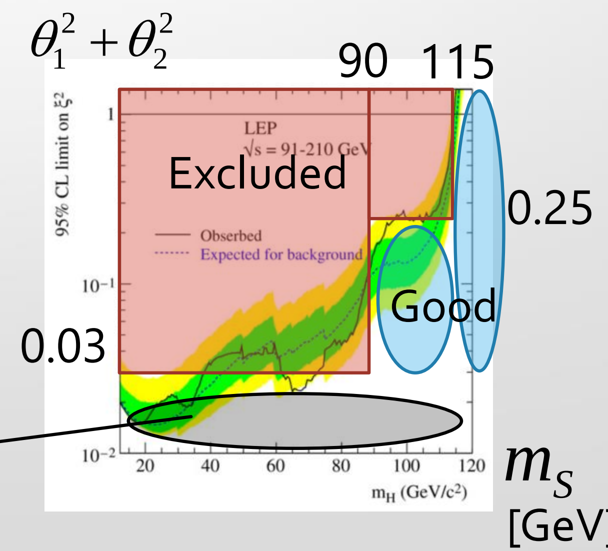
The LEP Higgs search

$$90 - 115\text{GeV} < m_S$$



Not enough to raise the Higgs mass

CERN-EP/2003-011

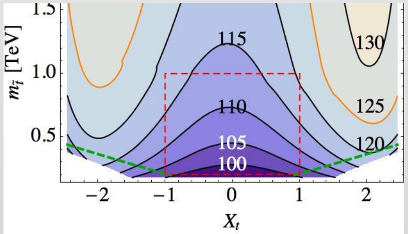
What would be the outcome of the Higgs results?

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

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

$b, \Lambda, m_{\hat{S}}^2$: parameters depending on the model

m_0^2 :Z boson mass + Q.C. (top, stop, ...)



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

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$b, \Lambda, m_{\hat{S}}^2$: parameters depending on the model

m_0^2 :Z boson mass + Q.C. (top, stop, ...)

The higgsino mass μ is constrained by the Higgs results!

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

Our setup

$$W = (\mathrm{MSSM-Yukawas}) + \lambda S H_u H_d + f(S)$$

Anything is OK.

No CPV is assumed.

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$$|X_t| < 1$$

$$0.01 < \lambda < 1$$

$$m_S < m_h = 126\mathrm{GeV}$$

$b \to s\gamma$

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

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

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Let us take

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

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Let us take $m_H = 800\text{GeV}$

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

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

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

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

Why does μ get small?

When m_H is rather heavy,

$$|\lambda\mu| \cong \frac{1}{2v}\left[\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2}\frac{1}{\tan\beta}\left(m_H^2-m_S^2\right)+|\theta_2|\left(m_h^2-m_S^2\right)\right]$$

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

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Fixed (not so large)

Lower bound

<u>Bounded above</u>

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Fixed (not so large)

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Bounded below

Upper bound

Thus μ is bounded above!

How small is μ?
- Simple example -

(L) If $\sqrt{\theta_1^2 + \theta_2^2} < 0.58$

(H) If $\sqrt{\theta_1^2 + \theta_2^2} < 0.44$

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

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$$|\lambda\mu| \cong \frac{1}{2v}\left[\frac{2|\theta_1\theta_2|}{\theta_1^2+\theta_2^2}\frac{1}{\tan\beta}\left(m_H^2-m_S^2\right)+|\theta_2|\left(m_h^2-m_S^2\right)\right]$$

$$|\mu| < 350\mathrm{GeV} \quad (\tan\beta = 10)$$

How large θ_1 and θ_2 can be?
-the Higgs signal strengths-

To get the preferred region of mixing angles, let us assume

- No systematic errors

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To get the preferred region of mixing angles, let us assume

- No systematic errors
- Independent Gaussian distributions
- Additional contributions to the effective couplings
  - are dominated by those of the higgsinos and the stops
  - are taken freely, but consistently with our parameter space

How large θ_1 and θ_2 can be?
-the Higgs signal strengths-

Then we obtain the 1σ and 2σ preferred regions

- using the chi-squared distribution with 5 or 6 DOF

- taking the parameters of higgsinos and stops that minimize the chi-squared.

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	WW/ggF	**ZZ/ggF**	**bb/VH-VBF**	**ττ/VH-VBF**	**γγ/X**	**γγ/Y**
ATLAS	0.99±0.30	1.43±0.38	1.09±0.34		1.66±0.37	1.72±0.79
CMS	0.68±0.20	0.92±0.28	1.15±0.62	1.10±0.41	0.65±0.34	1.80±0.89

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

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

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

hep-ex/1307.1427, ATLAS-CONF-2014-009, CMS-PAS-HIG-13-005

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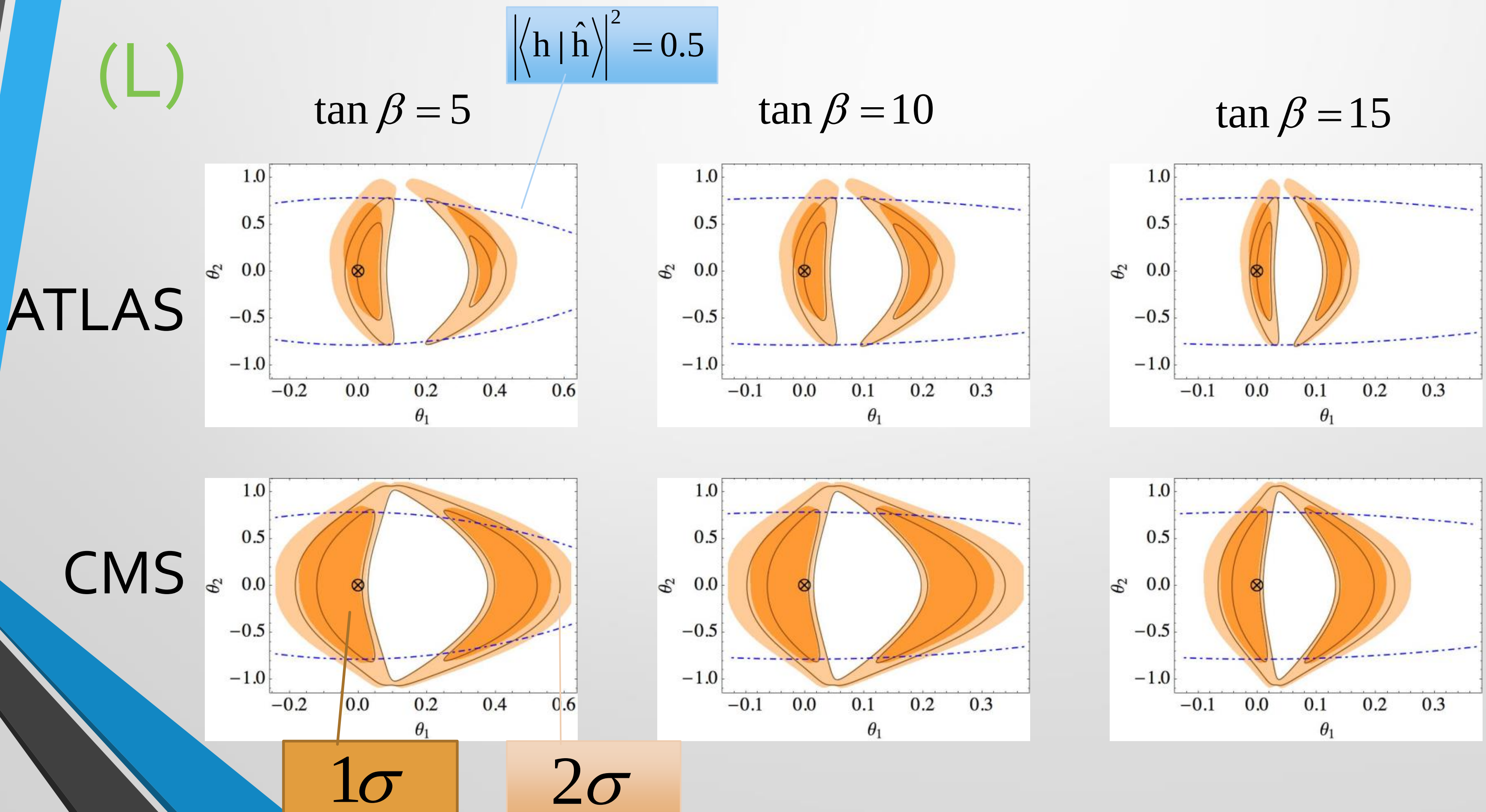
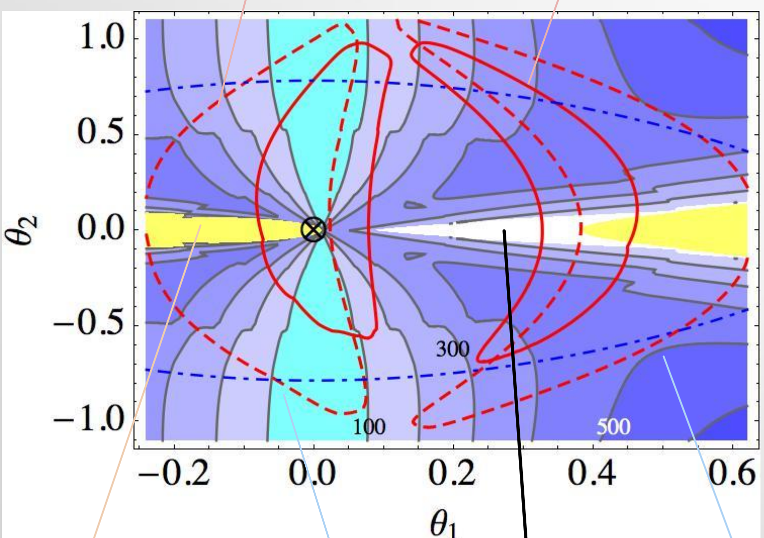


Numerical results (tanβ=5)

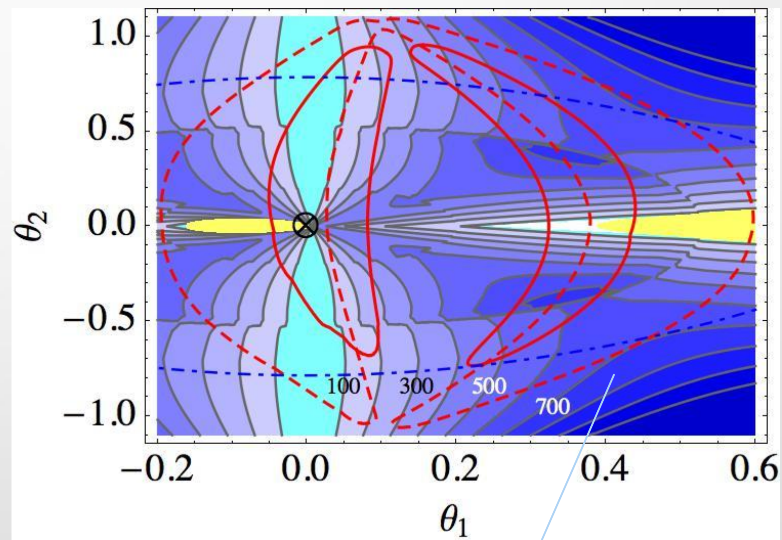
CMS 2σ (Dashed)

ATLAS 2σ (Solid)

(L)



(H)



No solution

λ>1

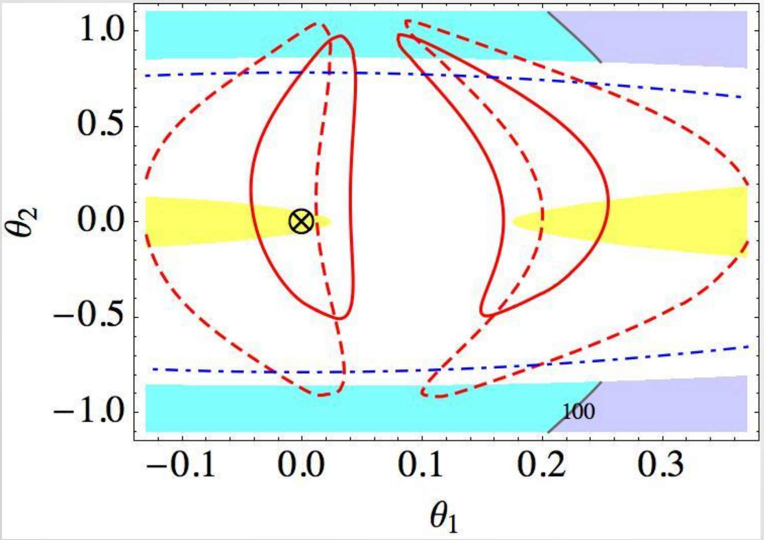
|μ|=500GeV

|μ|=700GeV

|μ|<100GeV Excluded by the constraint on chargino mass.

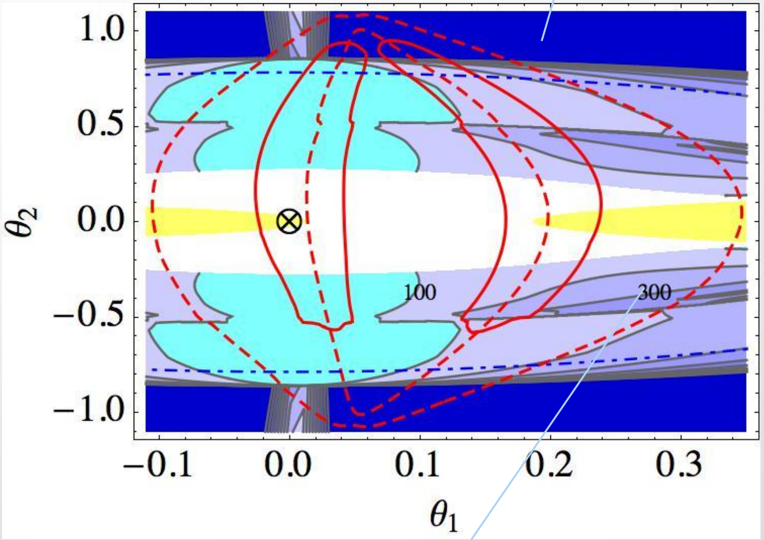
Numerical results (tanβ=10)

(L)



(H)

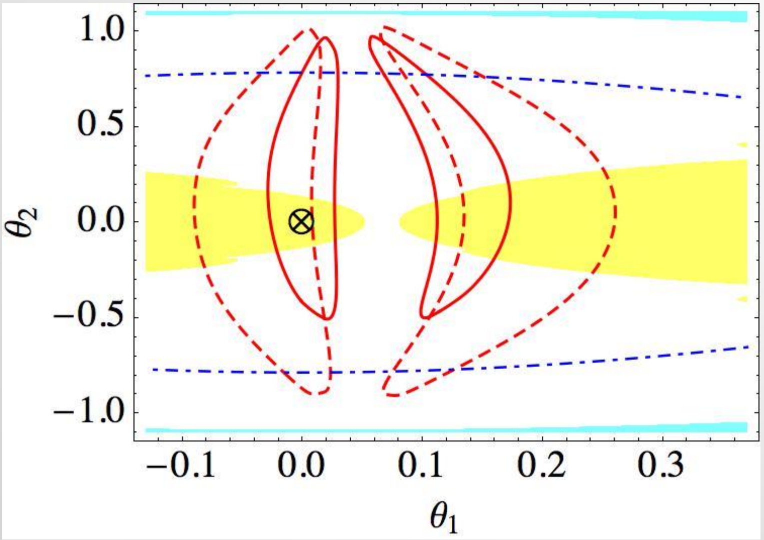
|μ|>1000GeV



|μ|=300GeV

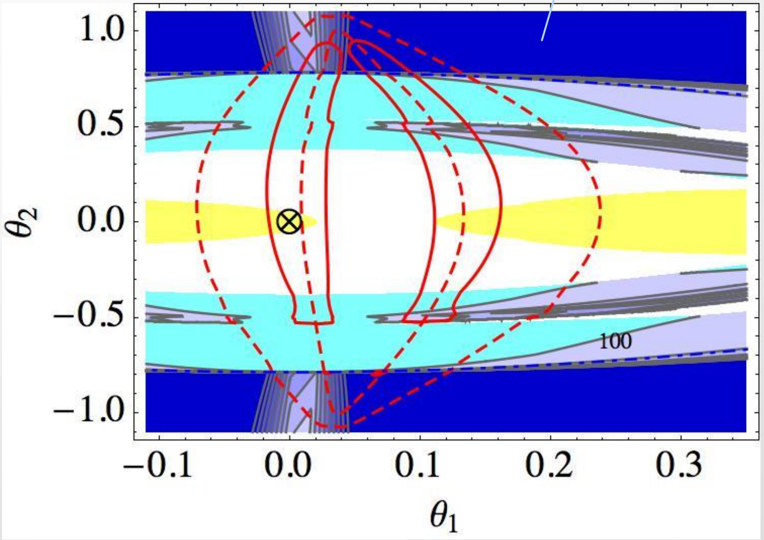
Numerical results (tanβ=15)

(L)



(H)

|μ|>1000GeV



Summary

The NMSSM can accommodate the 126GeV Higgs with TeV SUSY

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Then, in much of the parameter region, the higgsinos tend to be light!

Find the stop, find the deviation,
then the higgsinos are just beside you!

Backups

gamma gamma channels