General NMSSM with a mixed Higgs sector and implication of light higgsinos

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

arXiv: 1407.0955

Outline

- The motivation of our work
- How the higgsino mass is constrained
- Constraint from the Higgs signal strength
- Numerical results
- Summary

Where is SUSY?

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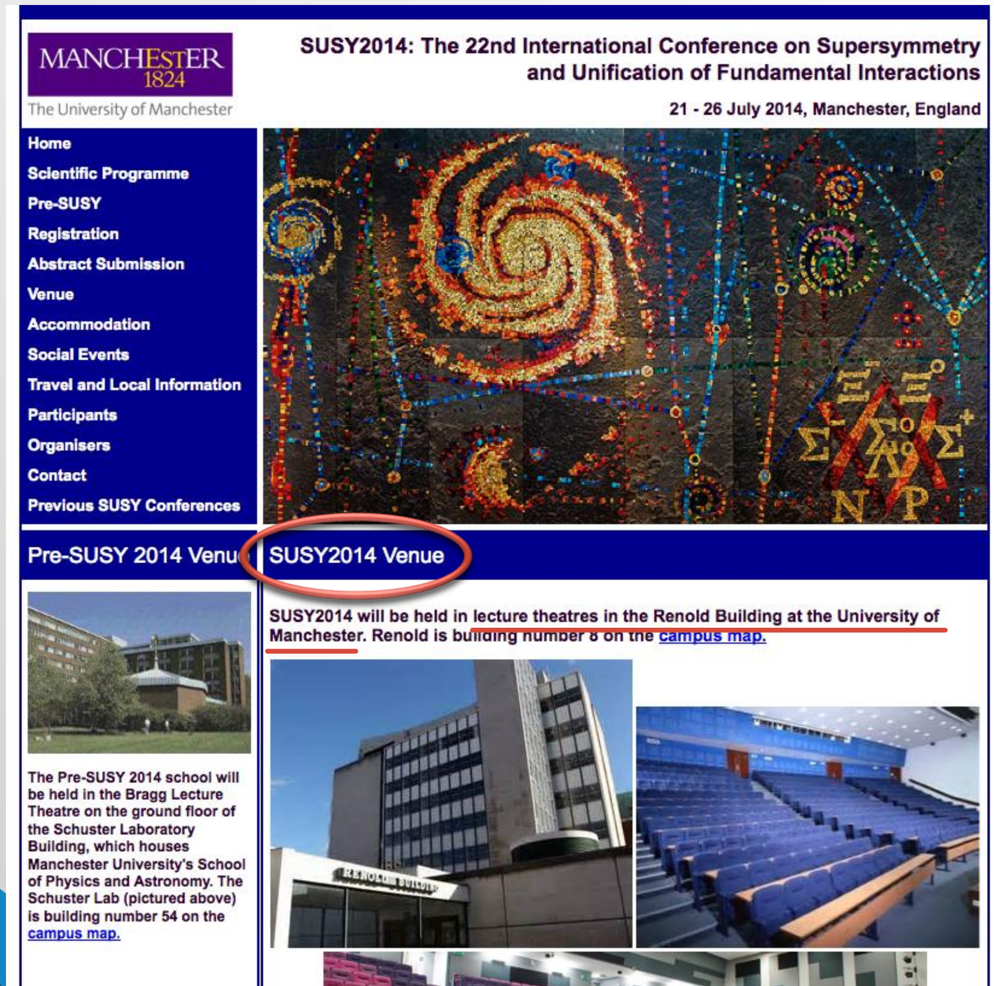
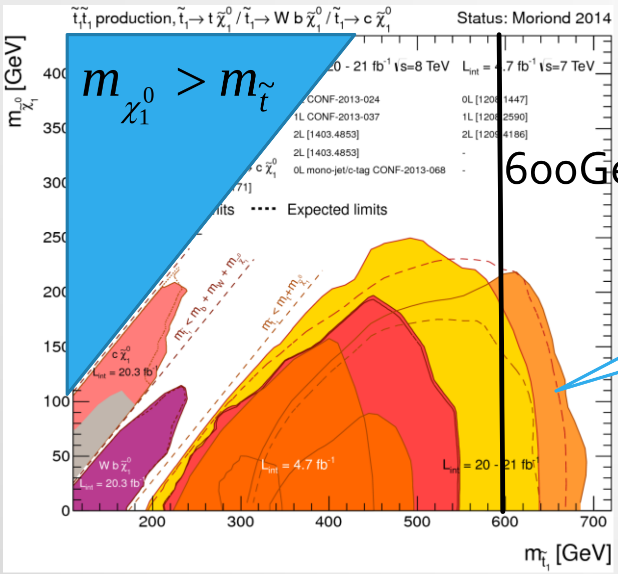


That's all we know…

Where is SUSY?



600GeV

Stops have not been discovered yet.

ATLAS, Moriond2014

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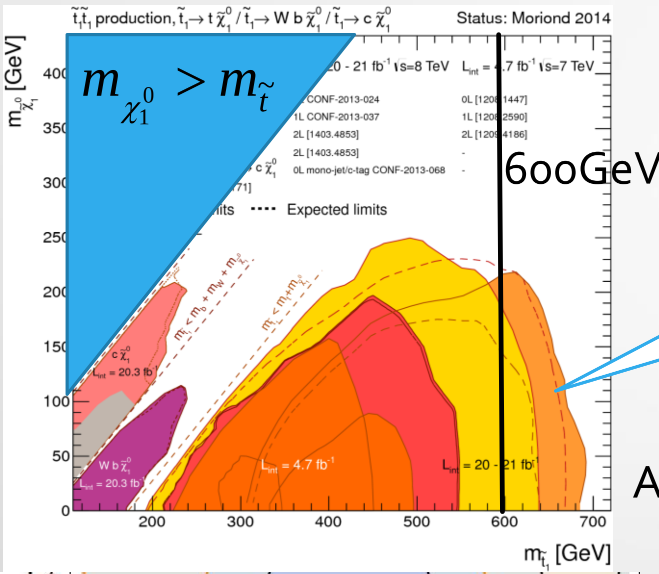

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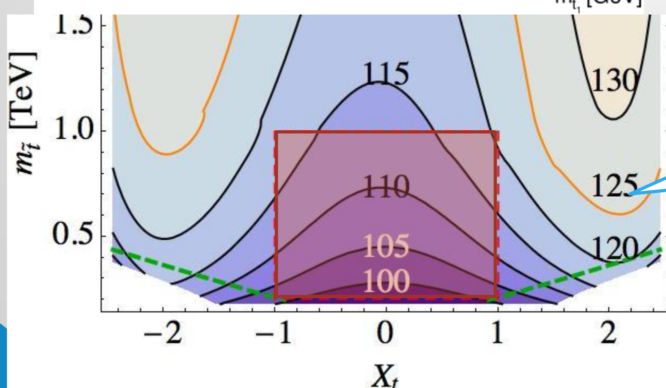


The Higgs boson mass requires heavy stop masses in the MSSM.

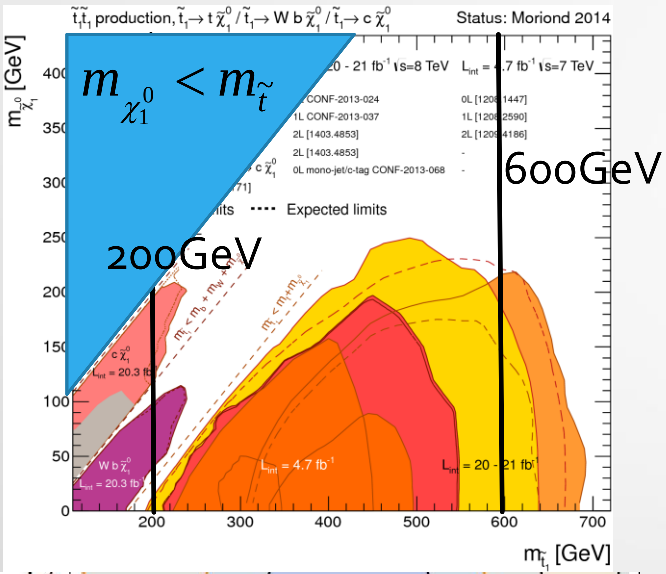
FeynHiggs 2.10.0

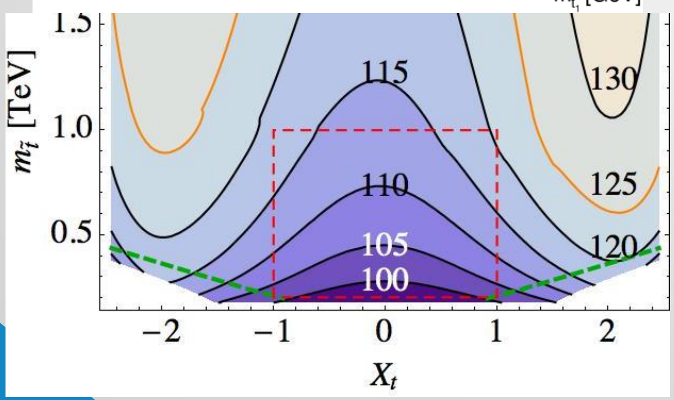
$$m_{\tilde{t}}^2 = \sqrt{m_{t_R}^2 m_{t_L}^2}$$

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

But, don’t worry!

Maybe, “she” is just around the corner!





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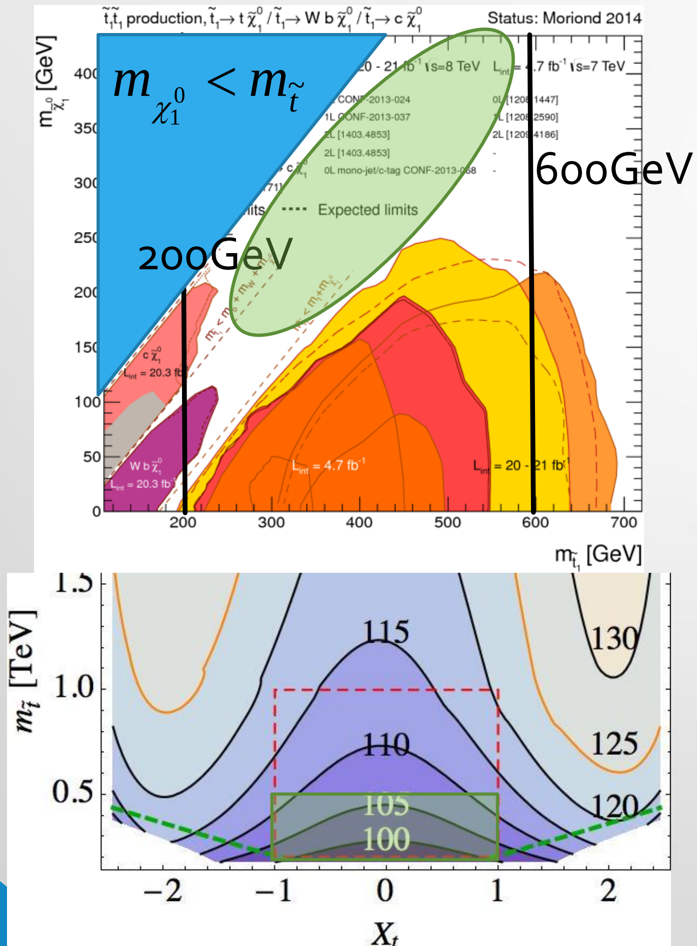

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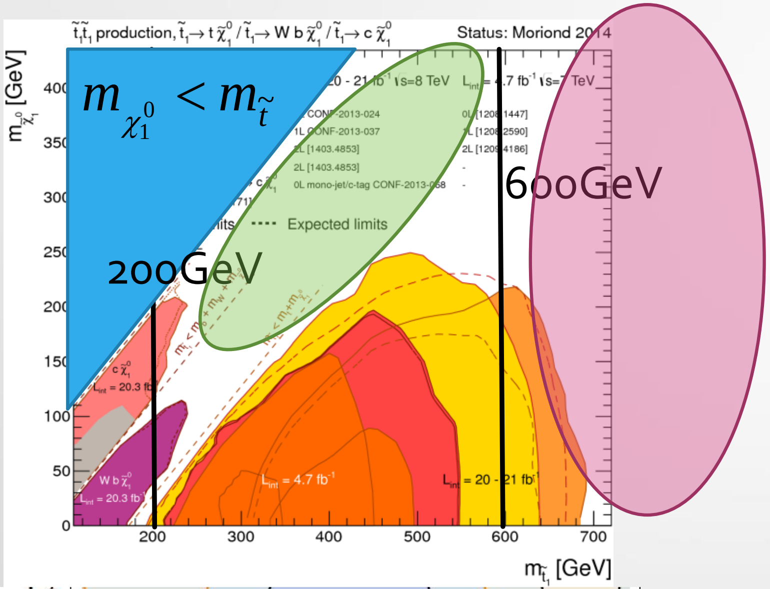

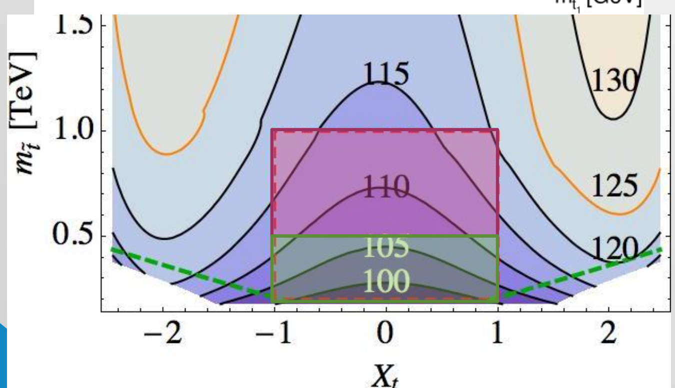

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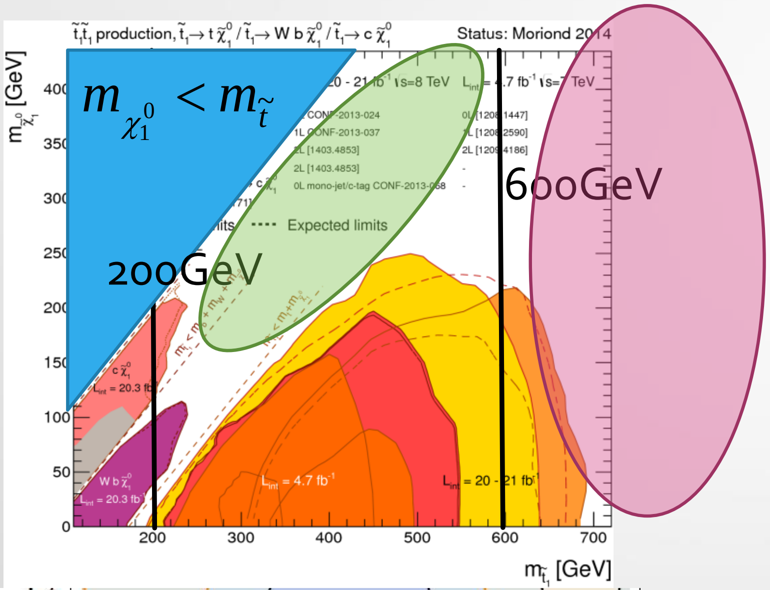

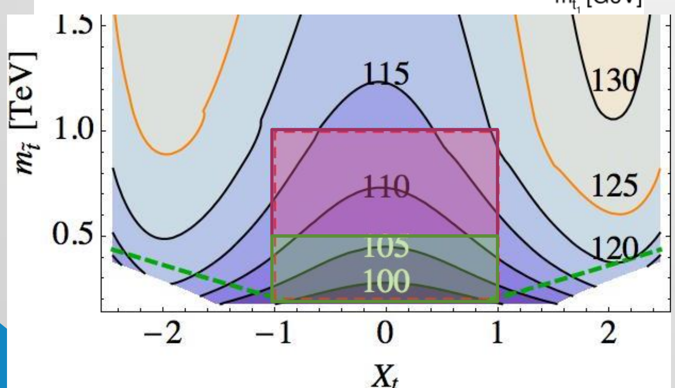

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We **need additional** contributions to the Higgs mass.

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

In order to push up the Higgs mass, we need

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

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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

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

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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observed

SM-like

MSSM Higgs

singlet

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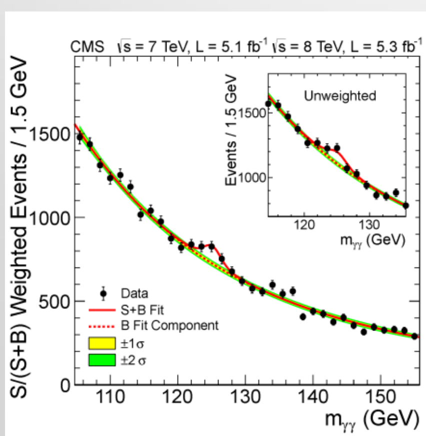
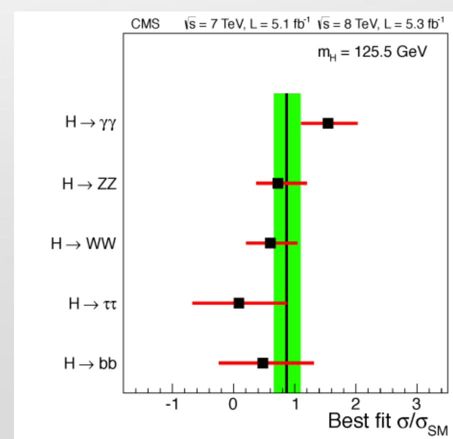
observed — SM-like — MSSM Higgs — singlet

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



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



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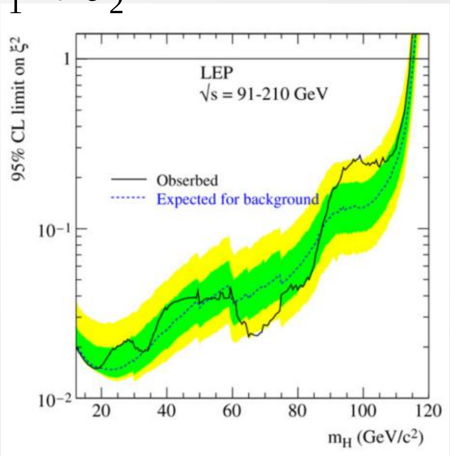
The LEP Higgs search

$\theta_1^2 + \theta_2^2$



m_S [GeV]

CERN-EP/2003-011

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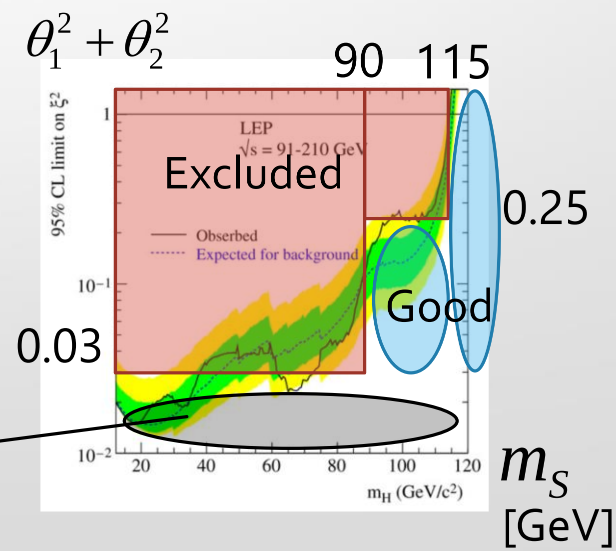
The LEP Higgs search

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

Not enough to raise the Higgs mass



CERN-EP/2003-011

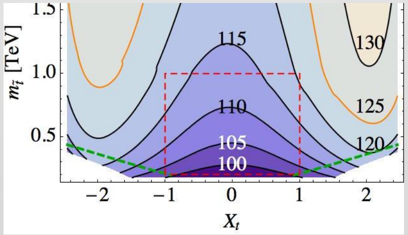
What would be the outcome of the Higgs results?

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

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

$b, \Lambda, m_{\hat{S}}^2$: 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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$$
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\end{array}
$$

$$
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\end{pmatrix}
$$

$b, \Lambda, m_{\hat{S}}^2$: 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.

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

Let us take

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

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

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

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

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

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)

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Lower bound

Bounded above

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

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Bounded below

Upper bound

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Lower bound

Bounded above

Lower bound

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Bounded below

Upper bound

Thus μ is bounded above!

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.

How large θ1 and θ2 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.

	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

How large θ1 and θ2 can be?
-the Higgs signal strengths-

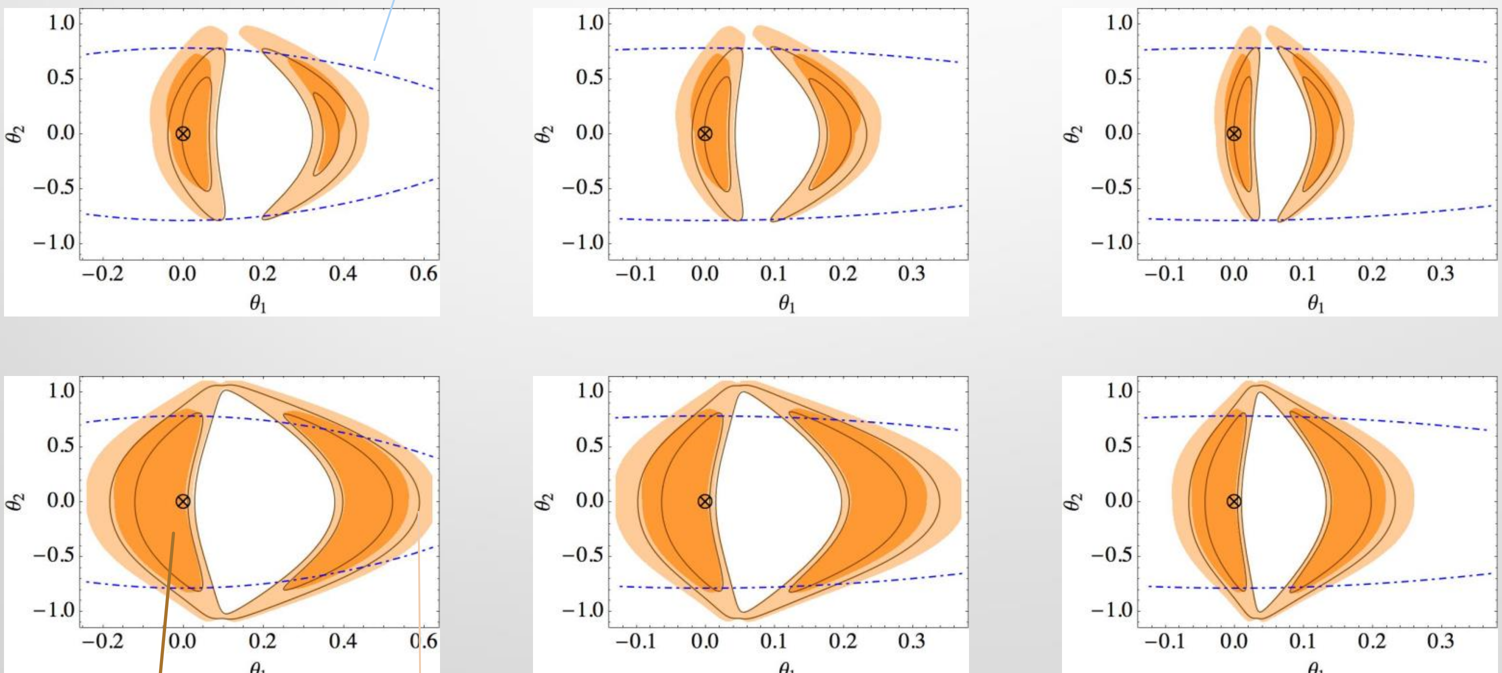
(L)

$\left|\left\langle h \mid \hat{h} \right\rangle\right|^2 = 0.5$

$\tan\beta = 5$ $\tan\beta = 10$ $\tan\beta = 15$

ATLAS

CMS



1σ 2σ

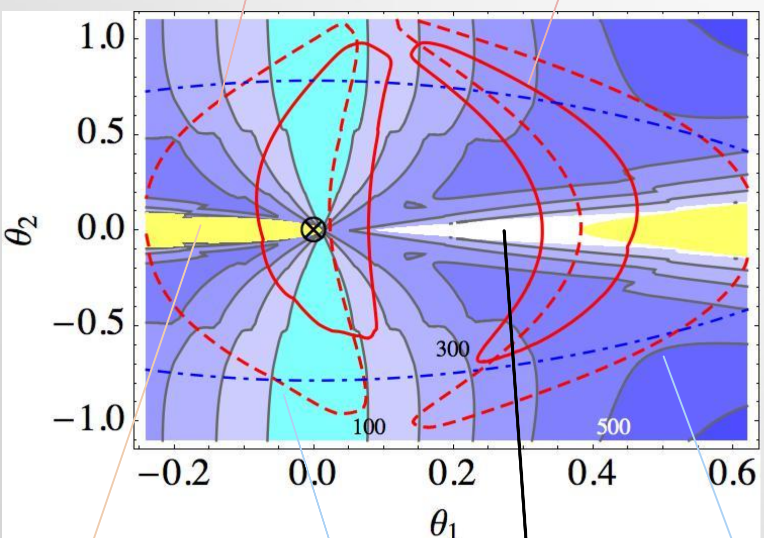
Numerical results ($\tan\beta=5$)

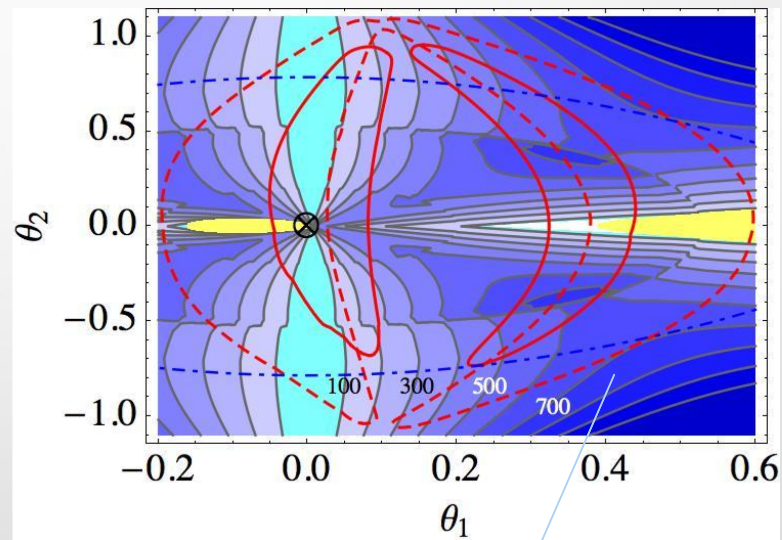
(L)

CMS 2σ (Dashed)

ATLAS 2σ (Solid)

(H)





No solution

$\lambda>1$

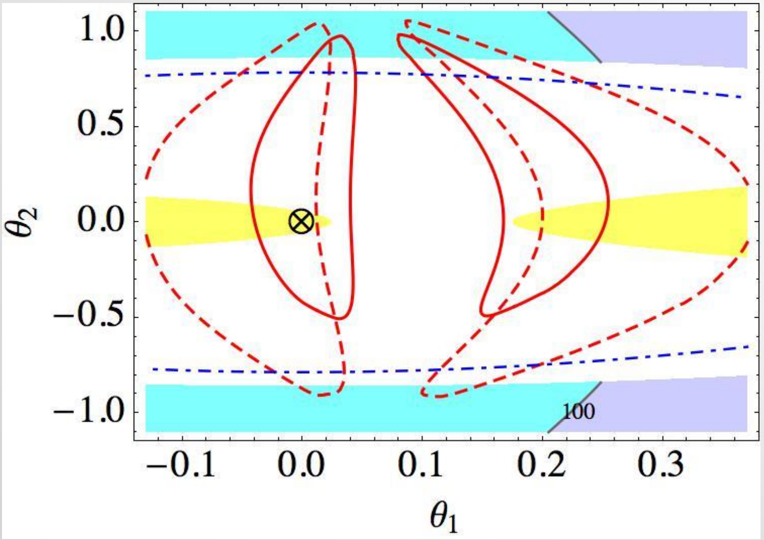
$|\mu|$=500GeV

$|\mu|$=700GeV

$|\mu|$<100GeV Excluded by the constraint on chargino mass.

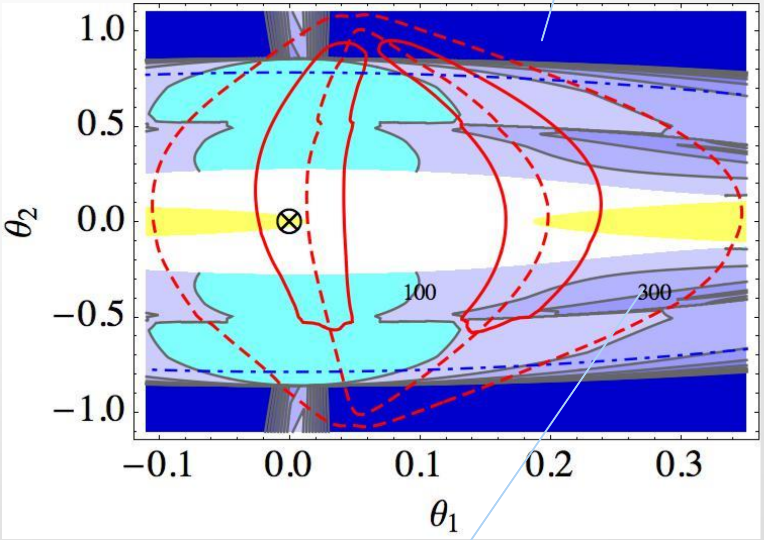
Numerical results (tanβ=10)

(L)



(H)

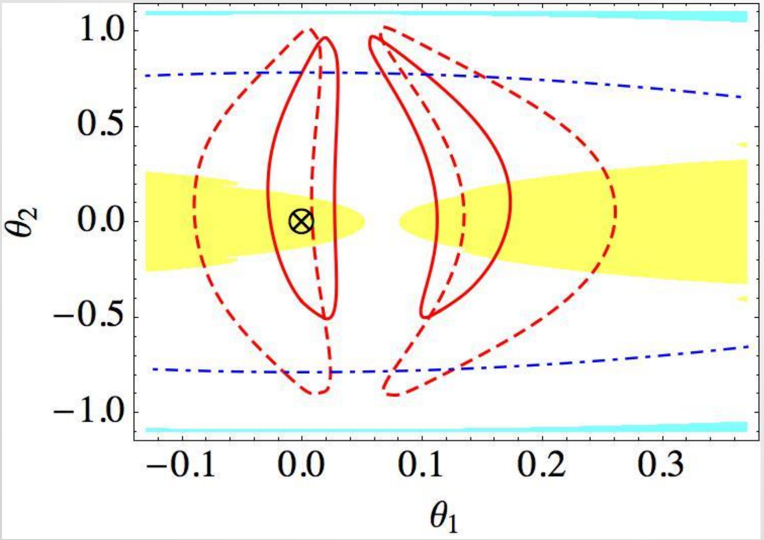
|μ|>1000GeV



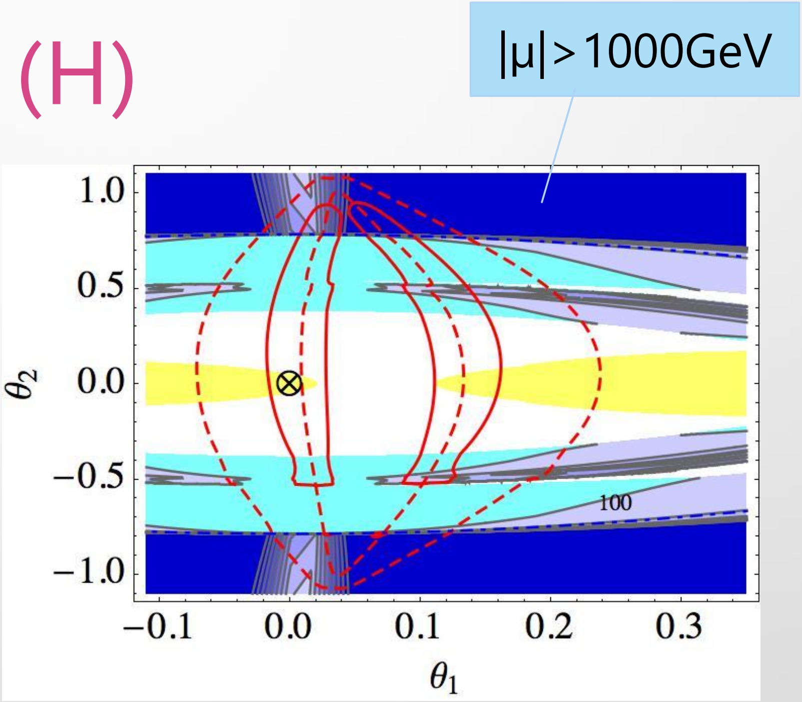
|μ|=300GeV

Numerical results (tanβ=15)

(L)



(H)



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- The Higgs signal strengths deviate from the SM values
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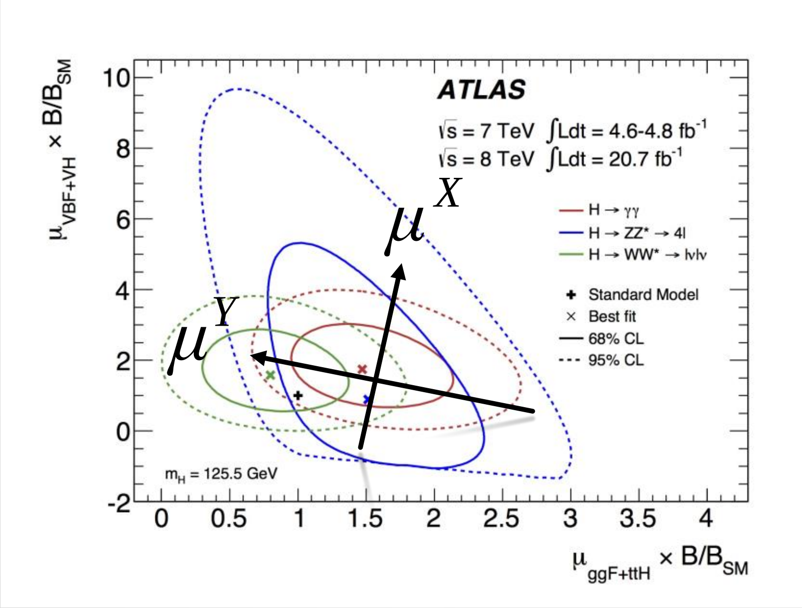
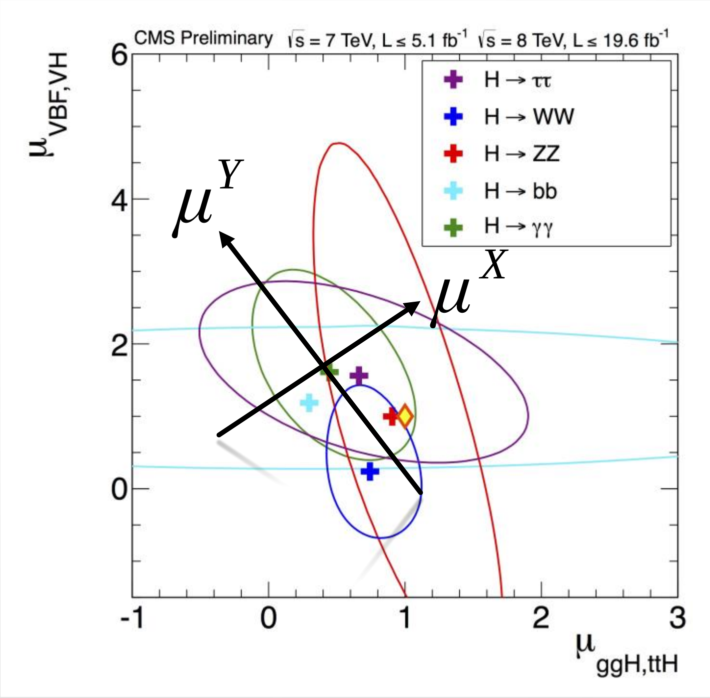
Then, in much of the parameter region, the higgsinos tend to be light!

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

Backups

gamma gamma channels





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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$$\lambda^2 \cong \frac{m_Z^2}{v^2}+\frac{\tan^2\beta}{4v^2}\underbrace{\left[\left(m_h^2-m_0^2\right)-\left(\theta_1^2+\theta_2^2\right)\left(m_h^2-m_S^2\right)\right]}_{>0}$$

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

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

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