Phenomenology of NMSSM in TeV scale mirage mediation

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In collaboration with

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T.Kobayashi, H.Makino, K.i.Okumura, T.Shimomura, Tsubasa Takahashi JHEP01 (2013) 081
T.Kobayashi, H.Makino, K.i.Okumura, T.Shimomura in preparation

Introduction

- Supersymmetry is attractive BSM candidate.
  - Big hierarchy + Unification
  - Light SM like Higgs (125 GeV): weak self-coupling
- Little hierarchy problem
  - Missing superpartner (mq~ >1.5 TeV LHC7+8)
  - Higgs is too heavy → multi-TeV stop ?
  - Fine tuning <1%

    c.f. eclipse ~ 6%

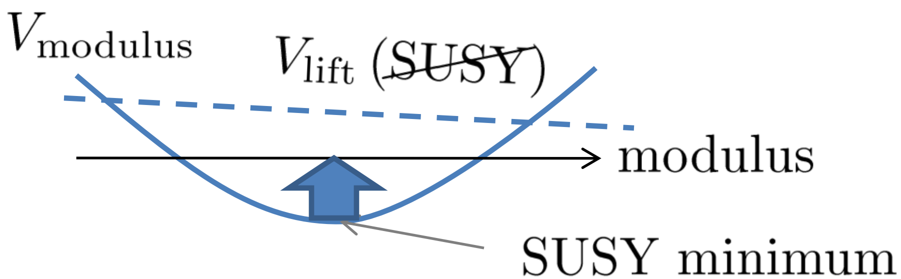
$$\frac{M_Z^2}{2} \simeq |m_{H_u}^2| - \mu^2 \quad (\tan\beta \neq 1)$$

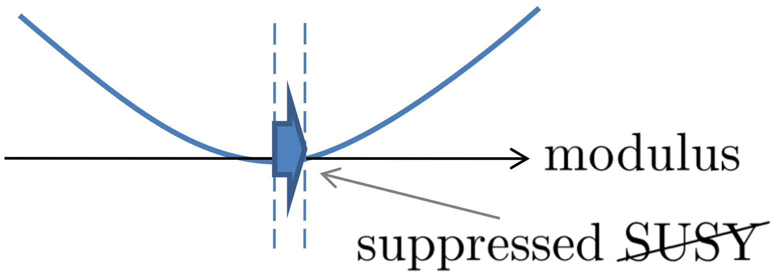
Solution: “TeV scale mirage mediation in NMSSM !”

Mirage mediation (MM)

K.Choi A.Falkowski H.P.Niles M.Olechowski and S.Pokorski (2005)

- Supergravity model (modulus + uplifting:KKLT).





- (Moduli mediation) + (Anomaly mediation)
  - Partial cancellation of RG running (1-loop only)

    →Mirage unification of soft masses@ $M_{\rm mir}$

    $M_{\rm mir} = {\rm TeV}$ → Natural Little Hierarchy

    " TeV scale Mirage mediation"

Mirage mediation (cont'd)

Modulus med.

Anomaly med.

$$M_a(M_{GUT}) = M_0 + \frac{m_{3/2}}{8\pi^2} b_a g_a^2$$

$$A_{ijk}(M_{GUT}) = (c_i + c_j + c_k) M_0 - (\gamma_i + \gamma_j + \gamma_k) \frac{m_{3/2}}{8\pi^2}$$

$$m_i^2(M_{GUT}) = c_i M_0^2 - \dot{\gamma} \left(\frac{m_{3/2}}{8\pi^2} \right)^2 - \frac{m_{3/2}}{8\pi^2} M_0 \, \theta_i$$

$$\alpha \equiv \frac{m_{3/2}}{M_0 \ln(M_{Pl}/m_{3/2})}$$

$$M_{\rm mir} = \frac{M_{GUT}}{(M_{Pl}/m_{3/2})^{\alpha/2}}$$

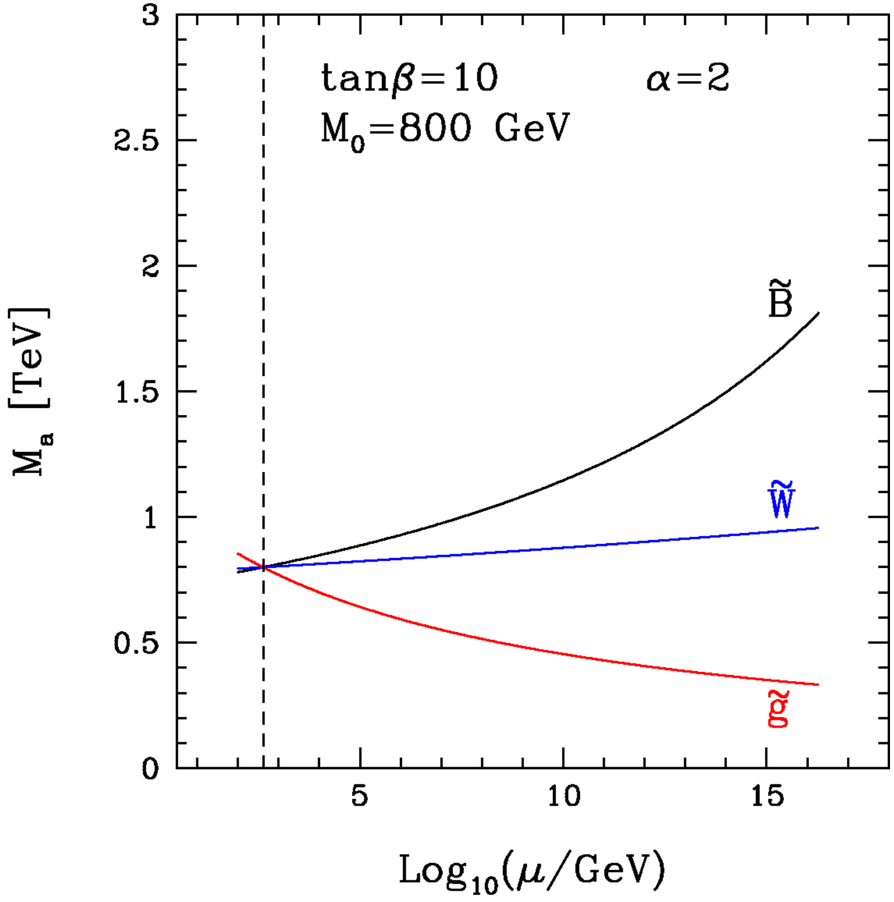
$\alpha = 2$ → TeV

$$\gamma_i = 2 \sum_a g_a^2 C_2^a(\phi_i) - \frac{1}{2} \sum_{jk} |y_{ijk}|^2$$

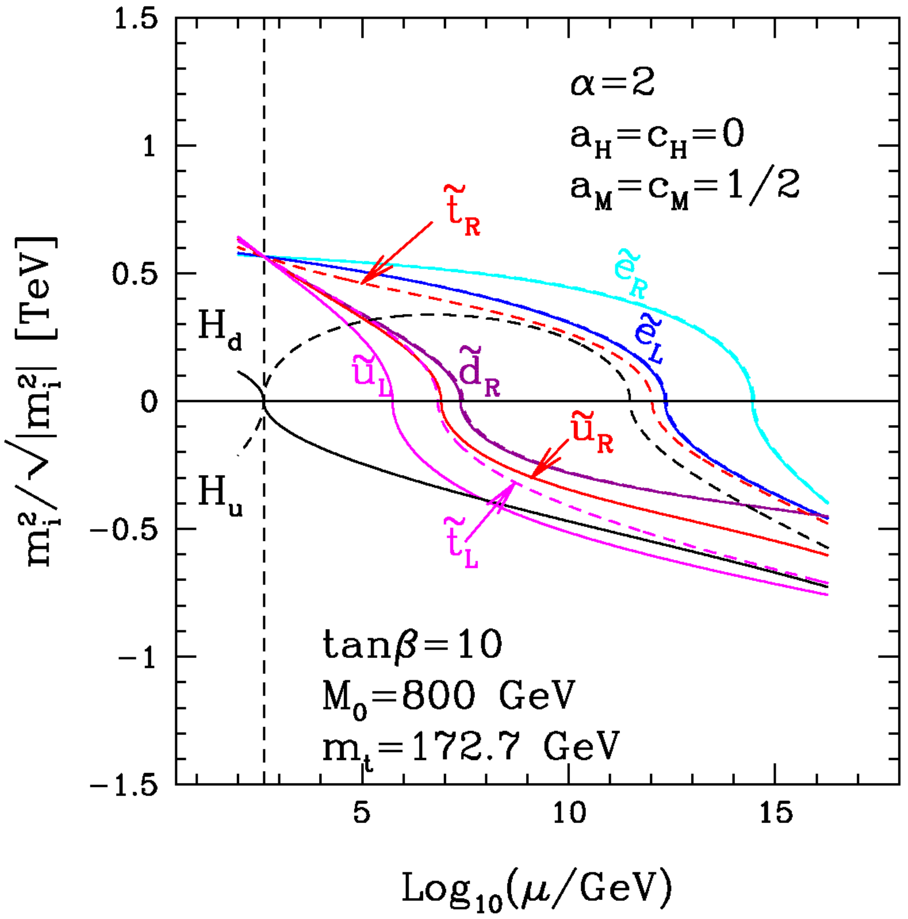
$$\theta_i = 4 \sum_a g_a^2 C_2^a(\phi_i) - \sum_{jk} (c_i + c_j + c_k) |y_{ijk}|^2$$

$$\dot{\gamma}_i = 8\pi^2 \frac{d\gamma_i}{d \ln \mu_R}$$

Gaugino Mass



Sfermion Mass



NMSSM

$$W_H = -\lambda S H_u H_d + \frac{\kappa}{3} S^3 \quad (Z_3)$$

- New F-term potential → Tree-level Higgs mass

$$\Delta V_F = \lambda^2 |H_u H_d|^2$$

  - Landau pole $\lambda \lesssim 0.6$
  - F-term ($\sin^2 2\beta$) max → D-term ($\cos^2 2\beta$) min
  - Mixing with S
- No gain in FT $\frac{M_Z^2}{2} \simeq |m_{H_u}^2| - \mu_{eff}^2 \quad \mu_{eff} = \lambda \langle S \rangle$
- Dimensionless → sol. of B_μ problem in MM

Improved Fine-tuning in TeV scale MM

K.Choi K.S.Jeong T.Kobayashi K.i.Okumura (2006)

$$c_{H_d} = 1, \; c_{H_u} = 0$$

$$B_\mu = A_\lambda$$

$$\mathcal{M}_H^2 = \begin{matrix} H_d \\ H_u \end{matrix} \overset{\begin{matrix} H_d & \quad H_u \end{matrix}}{\begin{pmatrix} M_0^2 + \mu^2 & M_0\,\mu \\ M_0\,\mu & \mu^2 \end{pmatrix}}$$

$$c_S = 0$$

$$\mathrm{Det}(\mathcal{M}_H^2) = M_H^2\,M_h^2 = (M_0^2 + \mu^2)\mu^2 - M_0^2\mu^2 = \mu^4$$

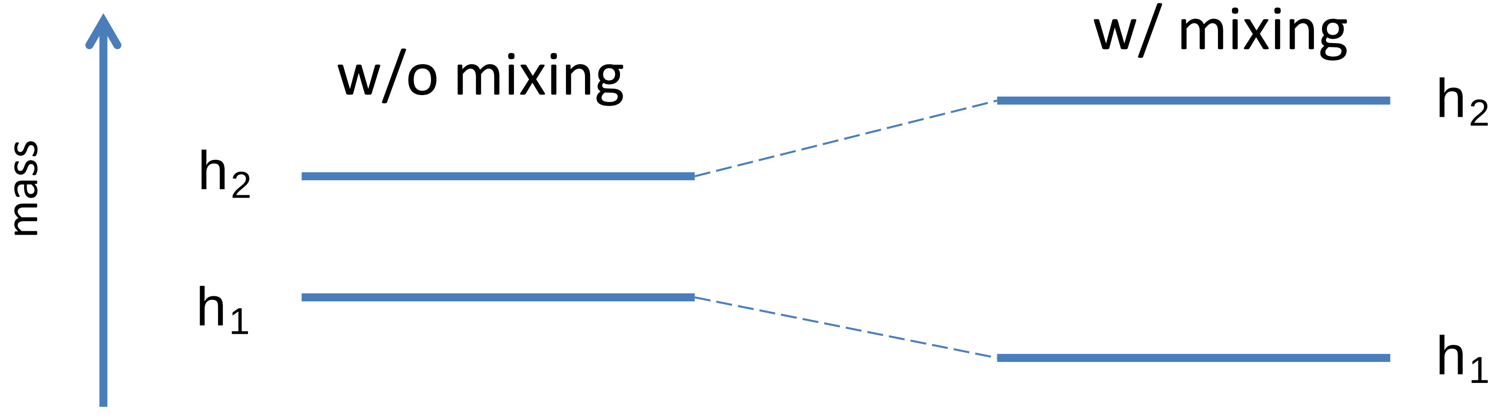
$$M_H \approx M_0 \rightarrow M_h \approx \mu \frac{\mu}{M_0} \quad !$$

Pot. minimum chooses: $$\frac{M_Z^2}{2} \simeq |m_{H_u}^2| + \overbrace{\left(-\mu^2 + \frac{m_{H_d}^2}{\tan^2\beta}\right)}^{\text{Cancel}}$$

Goldstone-like but accidental → No coupling suppression

Doublet-Singlet mixing

If the doublet-singlet mixing in mass matrix is large,



h_1: doublet-like ⟺ ~~125 GeV~~

h_1: singlet-like ⟺ ~~LEP bound~~

Doublet-Singlet mixing

$$\Delta\mathcal{L}_{\rm m} = -\frac{1}{2}\,(h,\ H,\ \Delta S_r)\,\mathcal{M}_S \begin{pmatrix} h \\ H \\ \Delta S_r \end{pmatrix}$$

$$h = Re(H_d)\cos\beta + Re(H_u)\sin\beta - v$$
$$H = -Re(H_d)\sin\beta + Re(H_u)\cos\beta$$
$$\Delta S_r = Re(S) - s$$

$$\mathcal{M}_S^2 =$$

$$\begin{pmatrix} \lambda^2 v^2 \sin^2 2\beta + g^2 v^2 \cos^2 2\beta & (\lambda^2 - g^2) v^2 \sin 2\beta \cos 2\beta & 2\lambda v\{\mu - (A_\lambda + 2\frac{\kappa}{\lambda}\mu)\sin\beta\cos\beta\} \\ (\lambda^2 - g^2) v^2 \sin 2\beta \cos 2\beta & \frac{\mu B_{\rm eff}}{\sin\beta\cos\beta} - \lambda^2 v^2 \sin^2 2\beta + g^2 v^2 (\sin^2 2\beta - \sin^2\beta) & -\lambda v (A_\lambda + 2\frac{\kappa}{\lambda}\mu) \\ 2\lambda v\{\mu - (A_\lambda + 2\frac{\kappa}{\lambda}\mu)\sin\beta\cos\beta\} & -\lambda v (A_\lambda + 2\frac{\kappa}{\lambda}\mu) & \lambda^2 \frac{A_\lambda}{\mu\tan\beta} v^2 \sin^2\beta + \frac{\kappa}{\lambda}\mu(A_\kappa + 4\frac{\kappa}{\lambda}\mu) \end{pmatrix}$$

$$\approx \frac{4v\mu}{\tan\beta}\left[\frac{\kappa}{\lambda} + \mathcal{O}(\frac{1}{\tan^2\beta})\right] \quad \Leftarrow \quad \mu \approx \frac{A_\lambda}{\tan\beta}$$

Mixing between the light doublet and singlet is suppressed by $\dfrac{\kappa}{\tan\beta}$

Numerical Analysis

- Choose Heavy param's (sol. of RGE) as inputs.

$$m_{H_d} = A_\lambda \approx M_0$$

- Solve three minimization conditions.

$$\frac{\partial V_{\rm NMSSM}}{\partial H_d} = \frac{\partial V_{\rm NMSSM}}{\partial H_u} = \frac{\partial V_{\rm NMSSM}}{\partial S} = 0$$

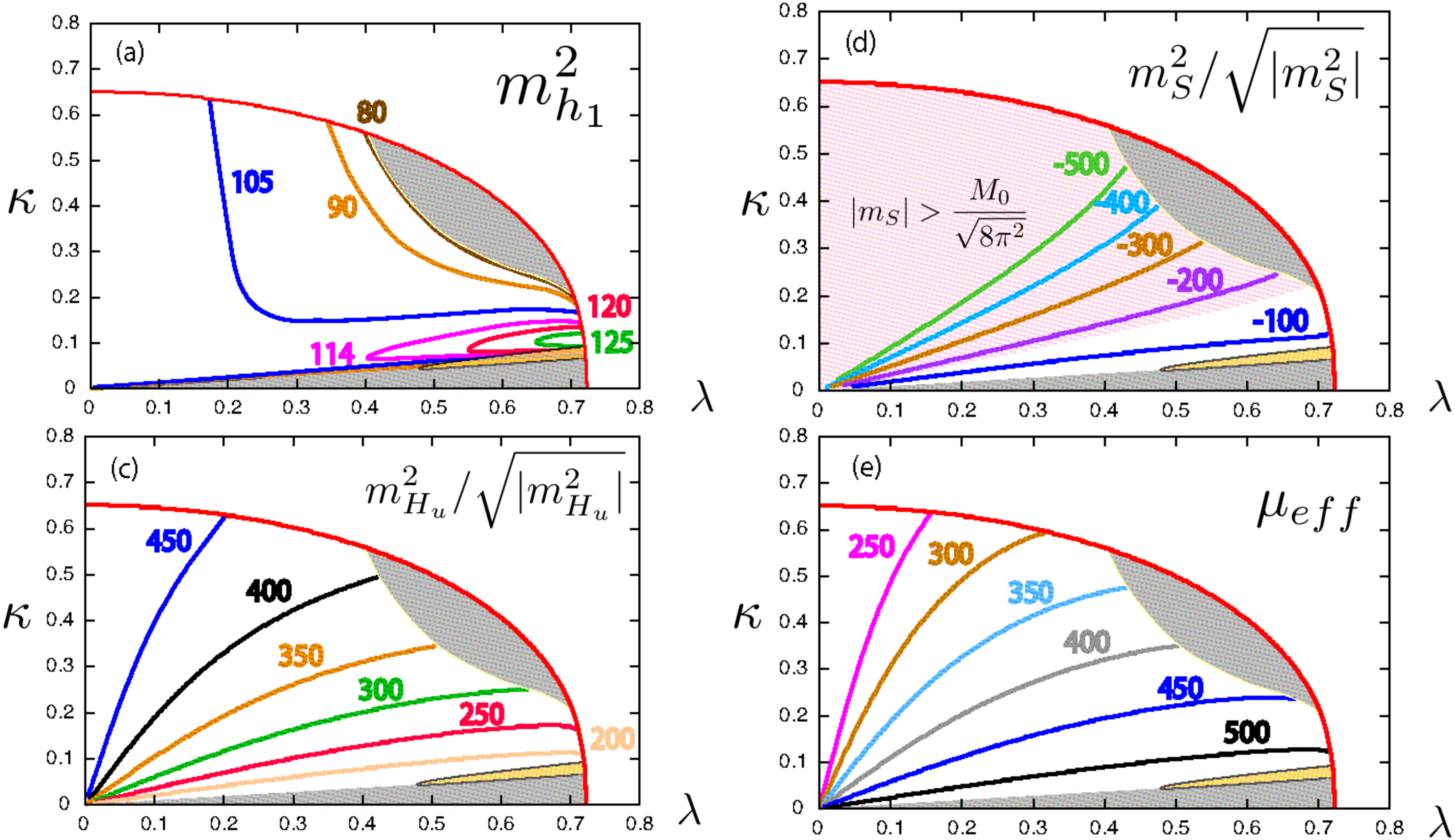
- Calculate light param's assuming correct EWSB

$$\mu_{eff} \approx \frac{M_0}{\tan\beta} \qquad m_{H_u}^2, m_S^2 \simeq \frac{M_0^2}{8\pi^2}$$

- Check favored regions within 1-loop ambiguity
- Calculation is performed by NMSSMTools

U.Ellwanger and C.Hugonie (2008)

Higgs mass



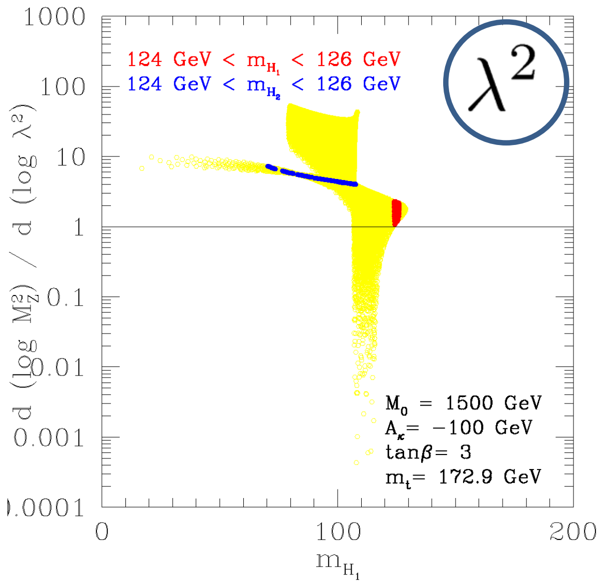
$\tan\beta = 3, \qquad M_0 = 1500\,GeV, \qquad m_t = 172.9\,GeV$

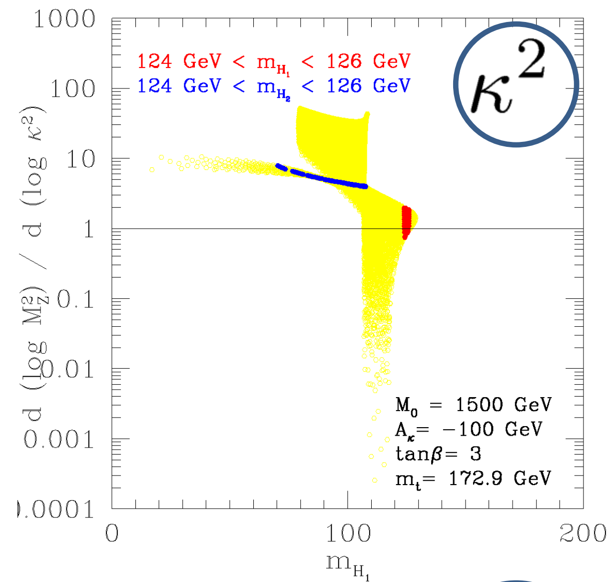
Fine Tuning

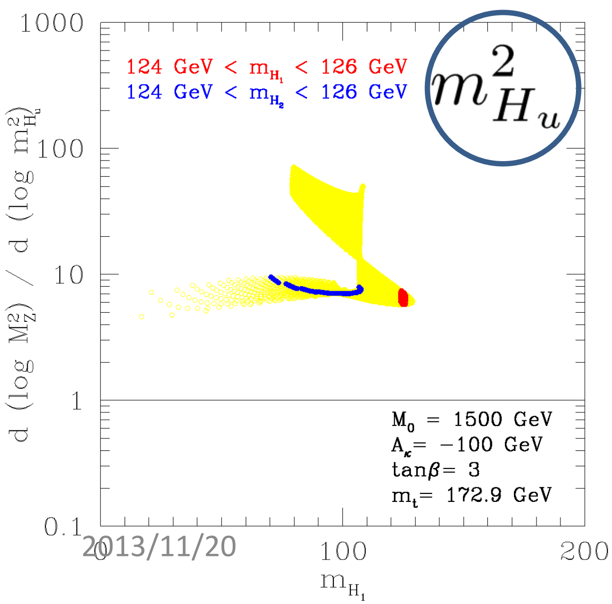
$\tan\beta = 3$

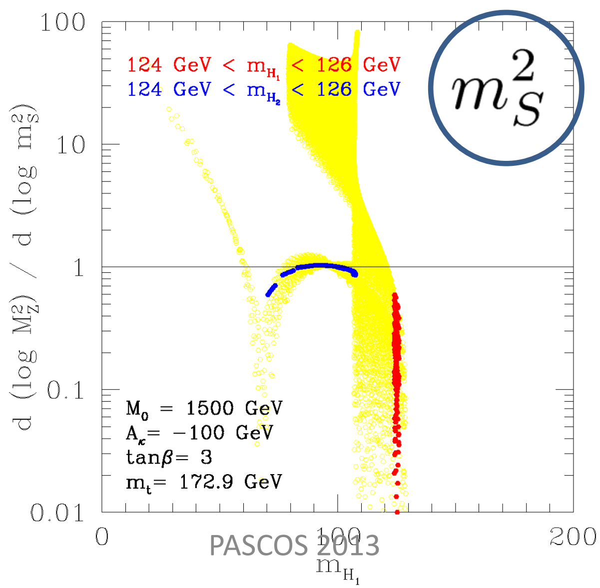
$M_0 = 1500\,\mathrm{GeV}$

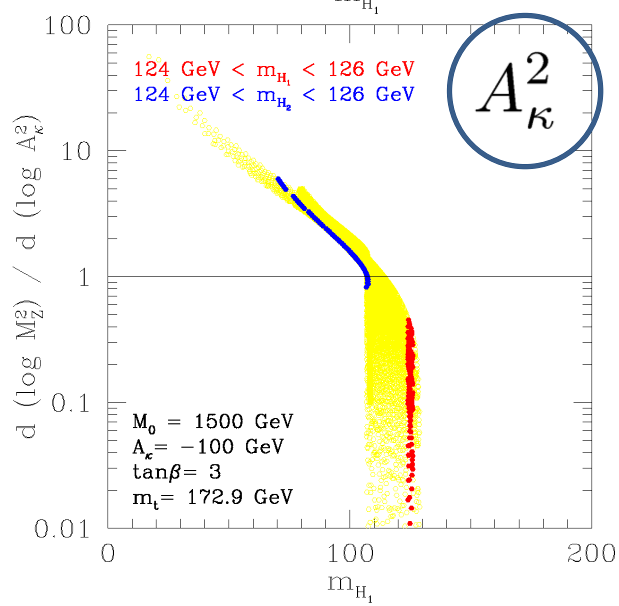
$$\Delta_X^{-1} \equiv \frac{\partial \ln M_Z^2}{\partial \ln X}$$



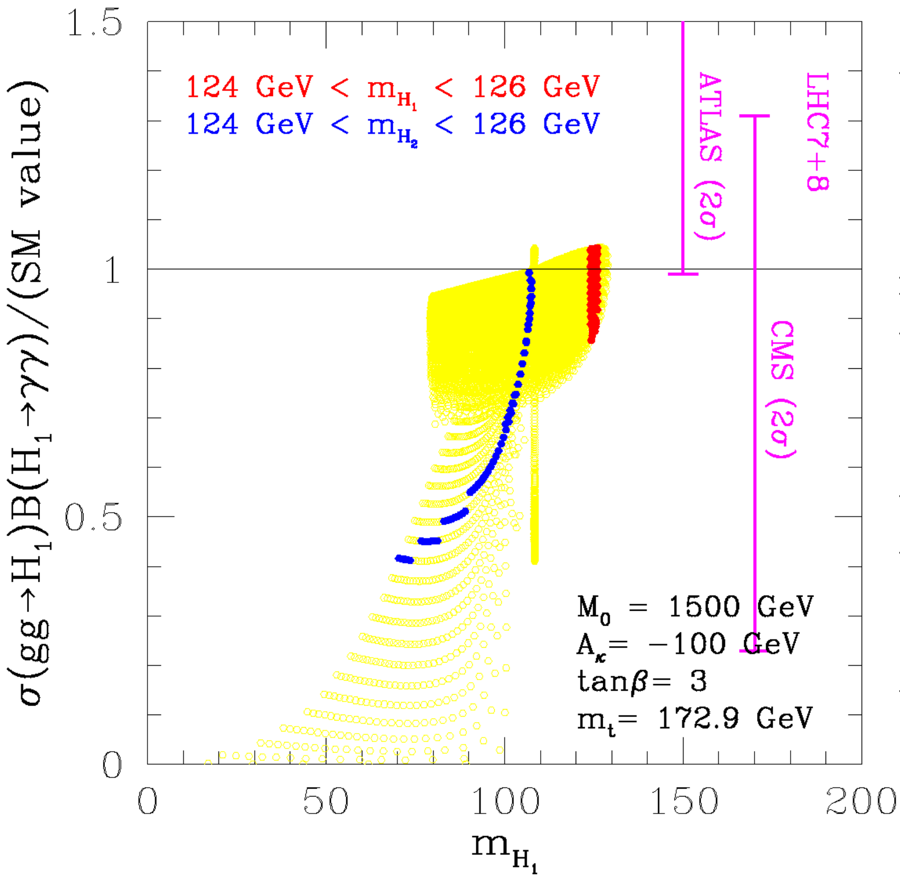


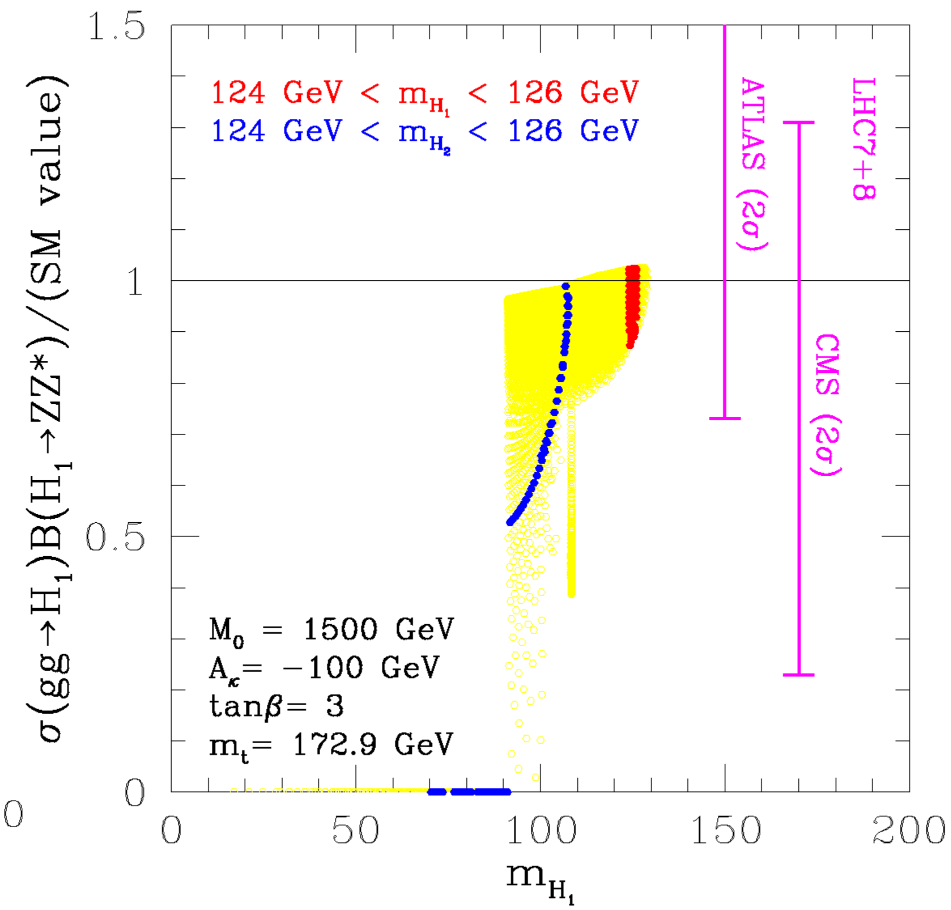






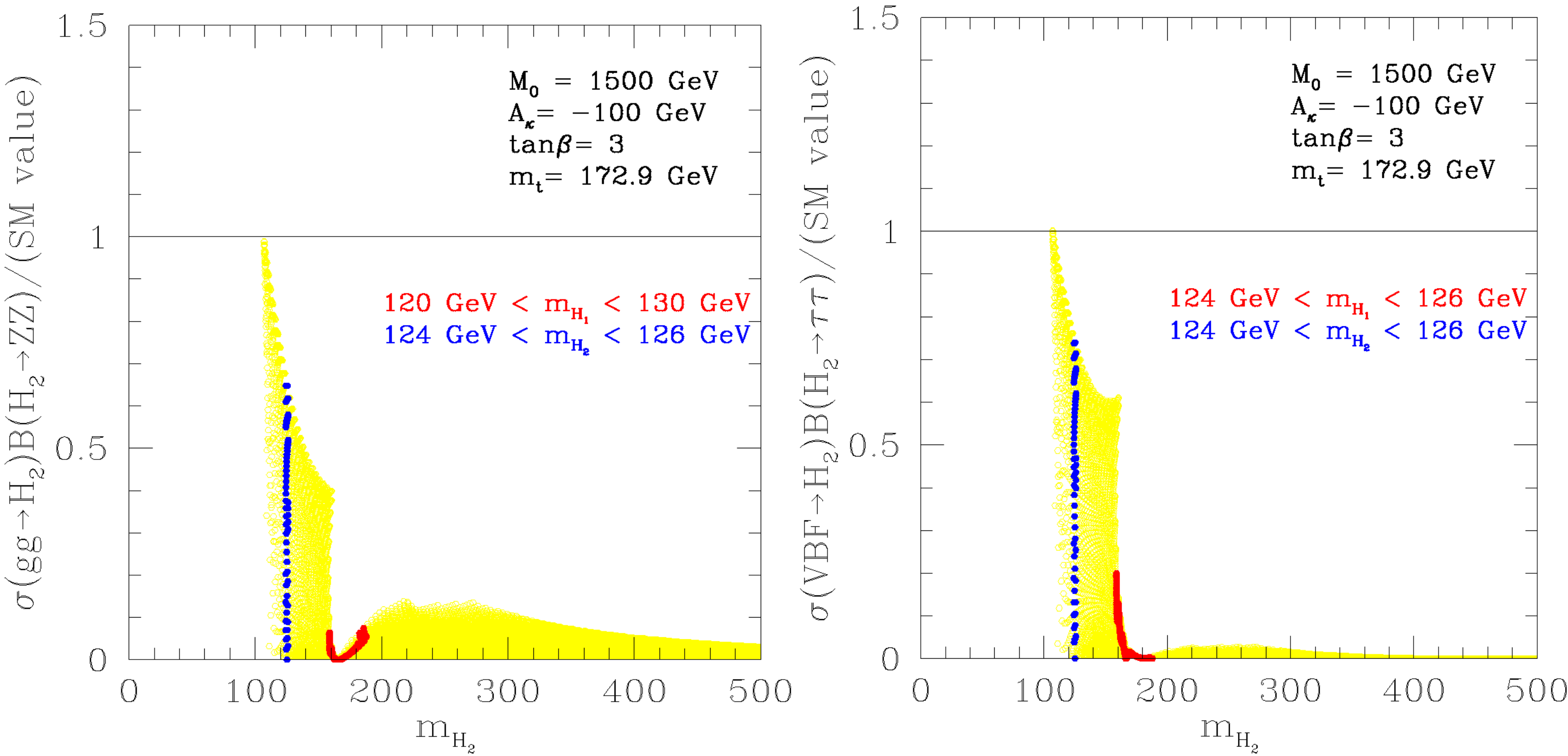
Higgs production & decays





Mixing with S is minimized at $m_{H_1} \approx 125\,\mathrm{GeV}$

Higgs production & decays (cont'd)



Mixing with Hu, Hd is minimized at $m_{H_1} \approx 125\,\mathrm{GeV}$

Conclusion

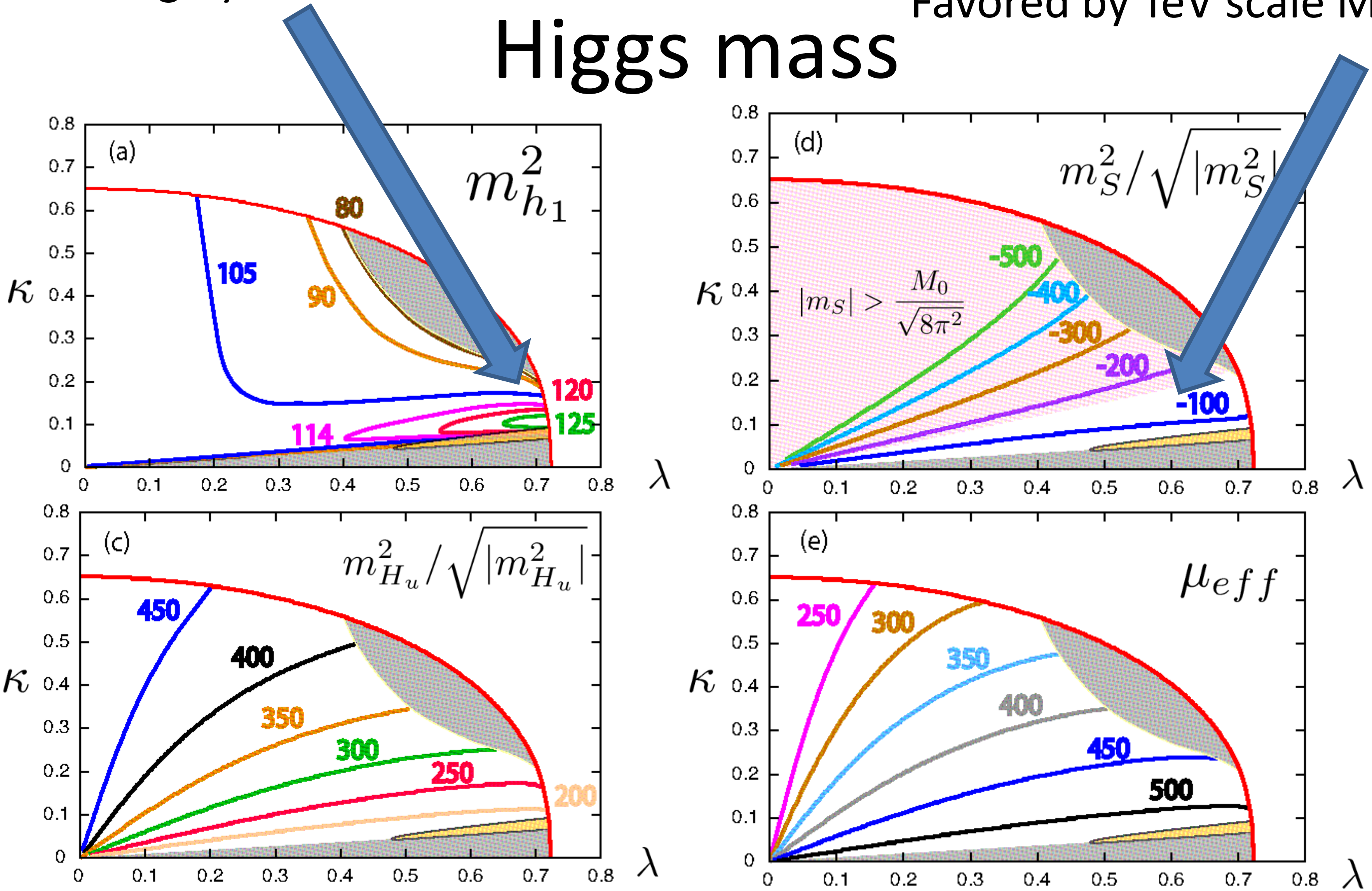
- NMSSM in TeV scale mirage mediation is attractive scenario
  - Natural little hierarchy.
  - Fine-tuning is improved (μ term).
  - 125 GeV Higgs is likely if λ is strong coupling @ GUT scale & correct EWSB is assumed.
  - 10% deviation in Higgs production & decays.
  - Singlet-like boson w/ small mixing is the smoking gun signal.

BACKUP

λ : strong dynamics at M_{GUT} ?

Favored by TeV scale MM

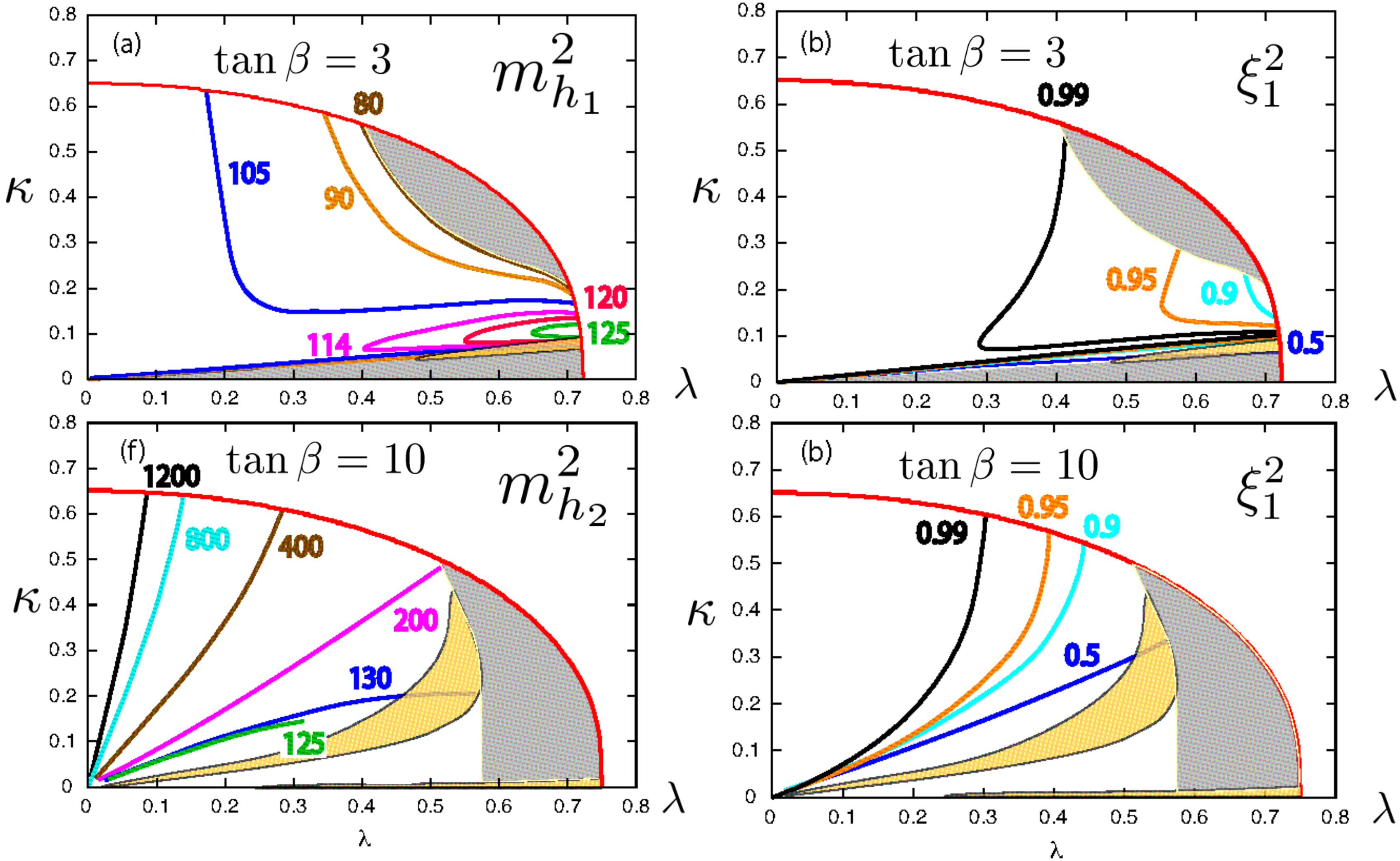
Higgs mass



$\tan\beta = 3, \quad M_0 = 1500\,GeV, \quad m_t = 172.9\,GeV$

$$g_{ZZh_i}^2 = \xi_i^2\, g_{SM}^2$$

Doublet-Singlet mixing

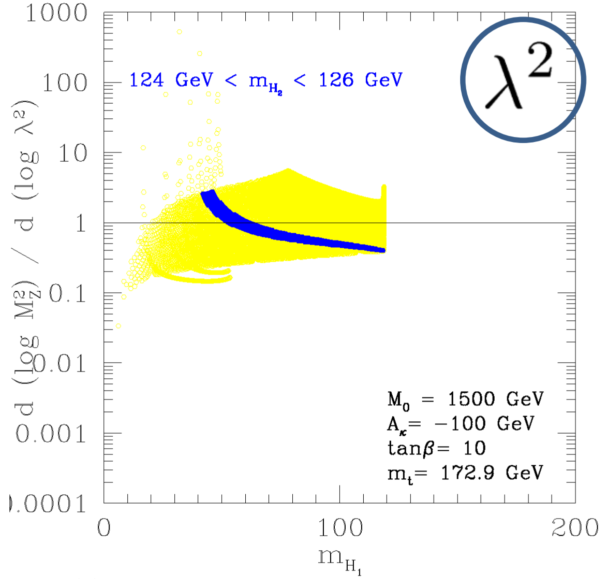


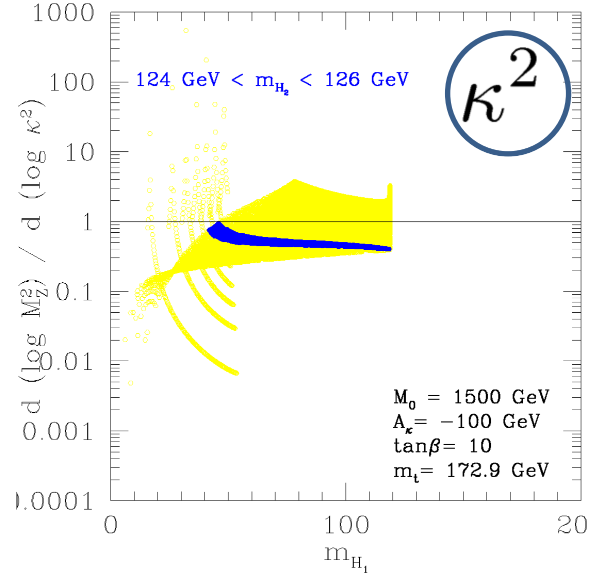
Fine Tuning (cont'd)

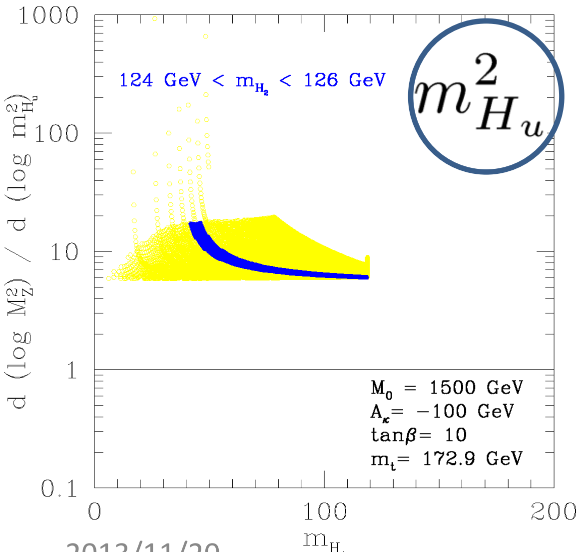
$$\tan\beta = 10$$

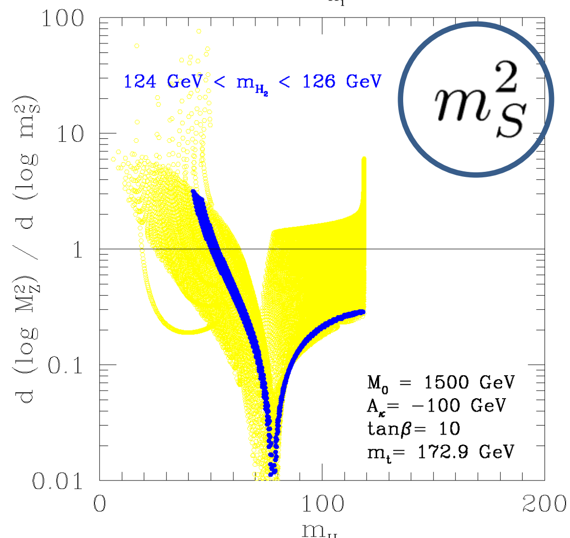
$$M_0 = 1500\,\mathrm{GeV}$$

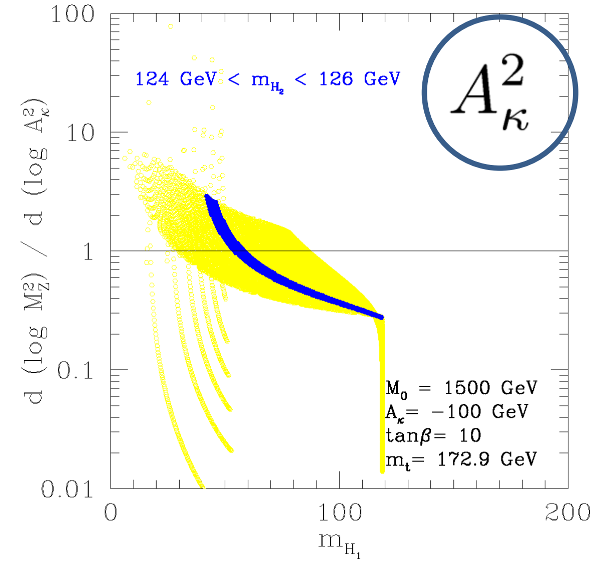
$$\Delta_X^{-1} \equiv \frac{\partial \ln M_Z^2}{\partial \ln X}$$



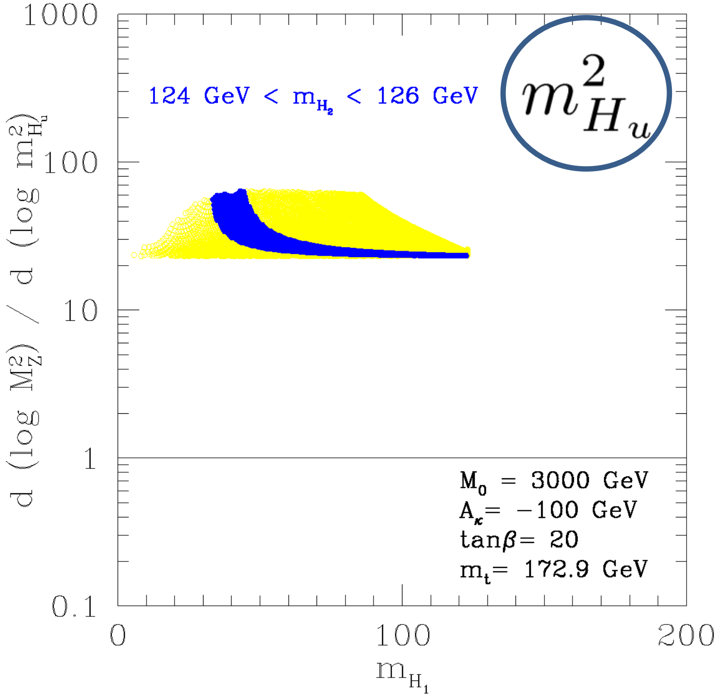


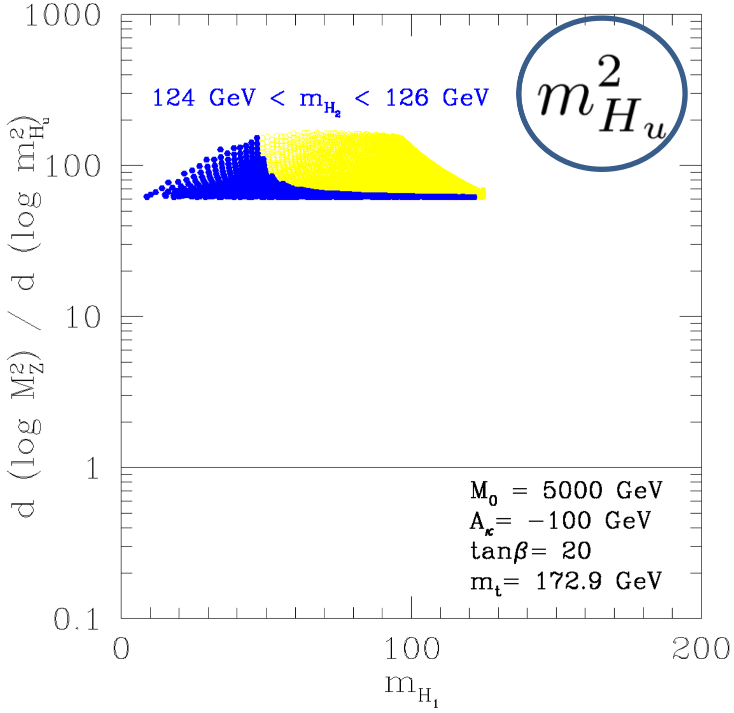






Fine Tuning (cont'd)



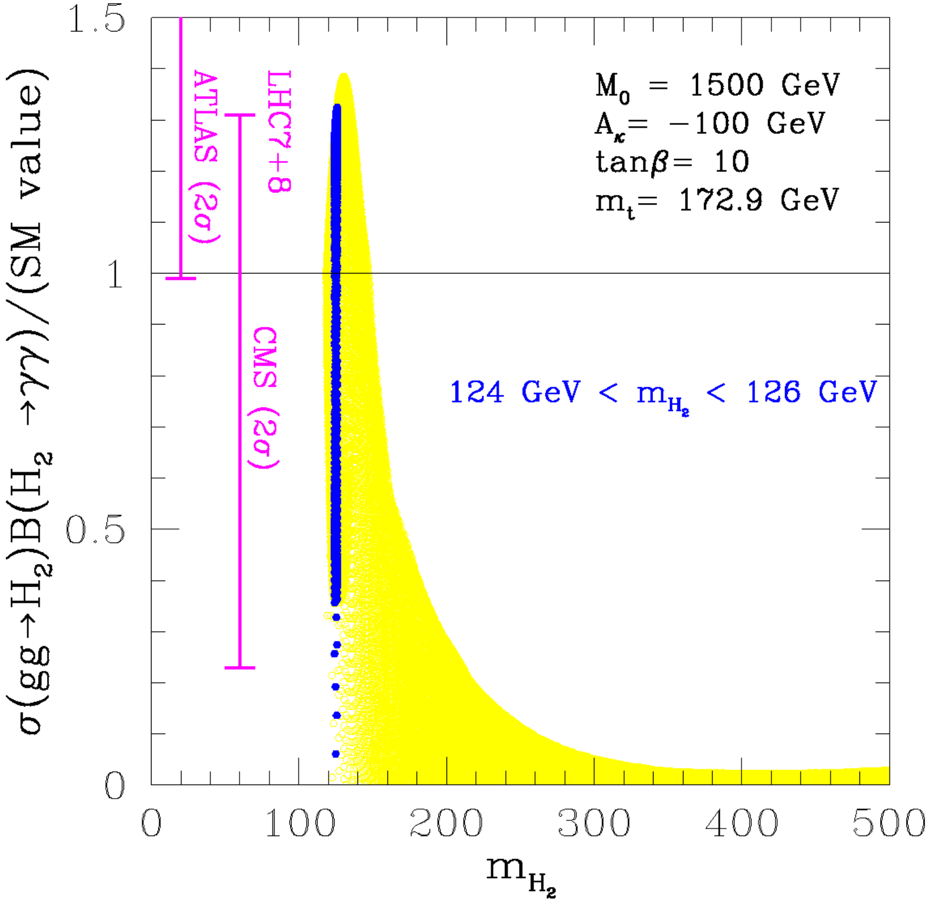


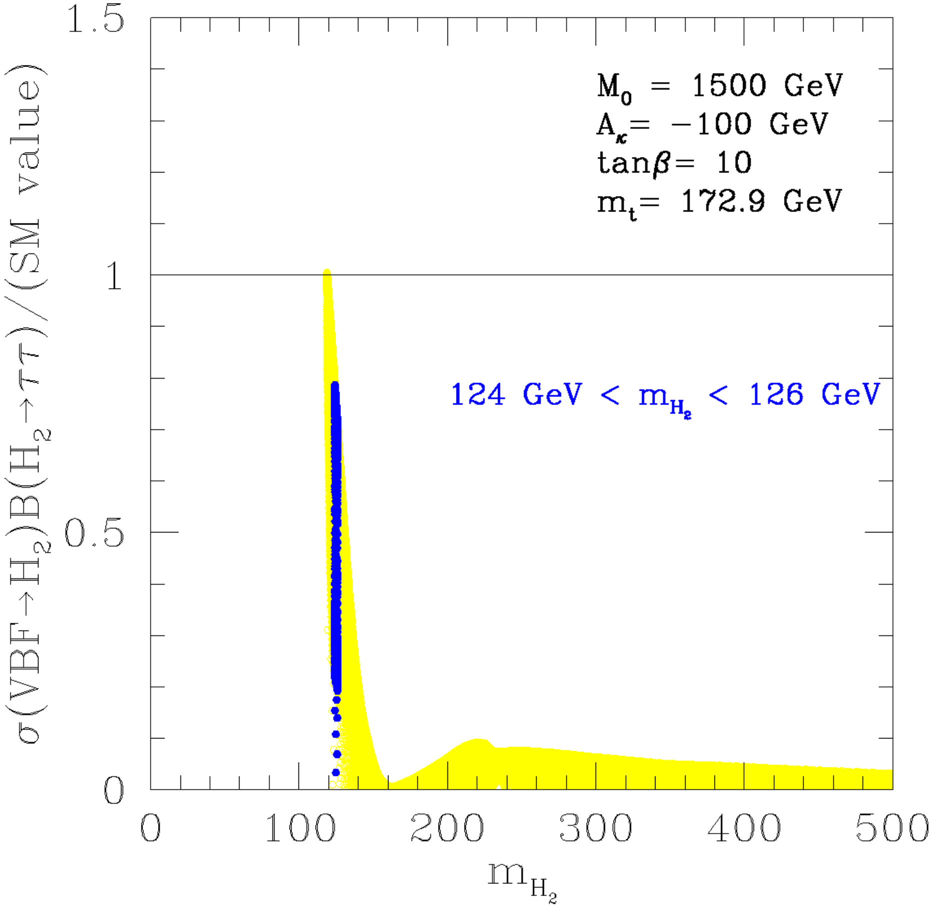
$\sim 5\,\%$ @ $M_0 = 3\,\text{TeV}$

$\sim 2\,\%$ @ $M_0 = 5\,\text{TeV}$

Not fully satifsactry but a level accepted by the SUSY community.

Higgs production & decays (cont'd)

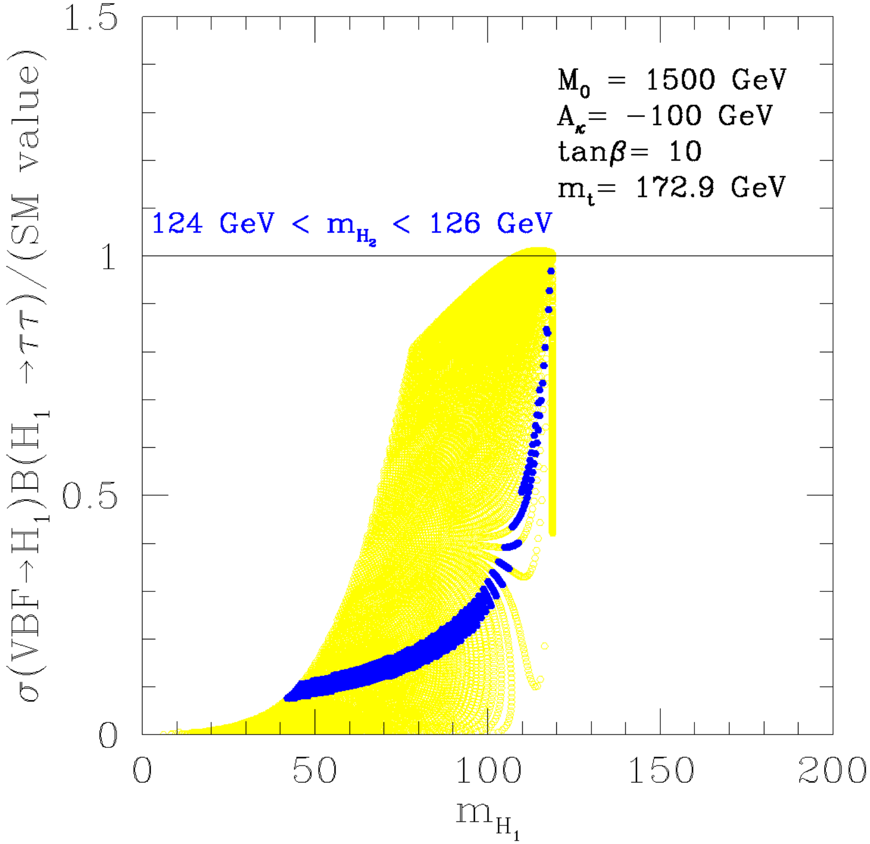


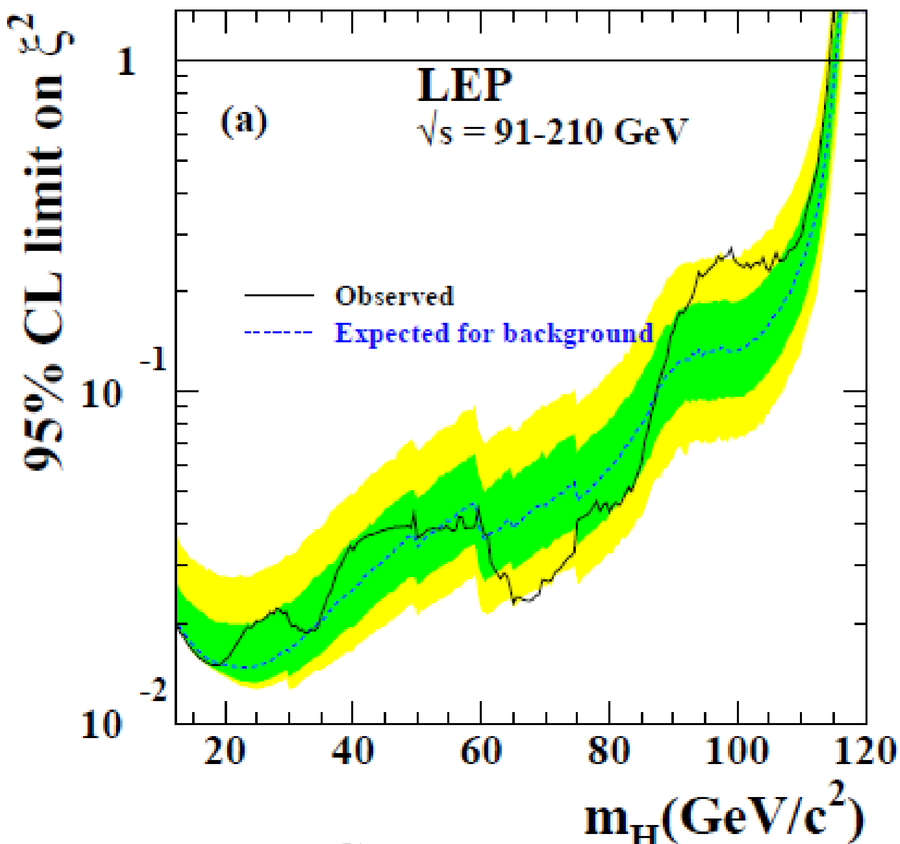


Small mixing is required to achieve $m_{h_2} = 125$ GeV

Higgs production & decays (cont'd)

U.Ellwanger et.al. (2011)

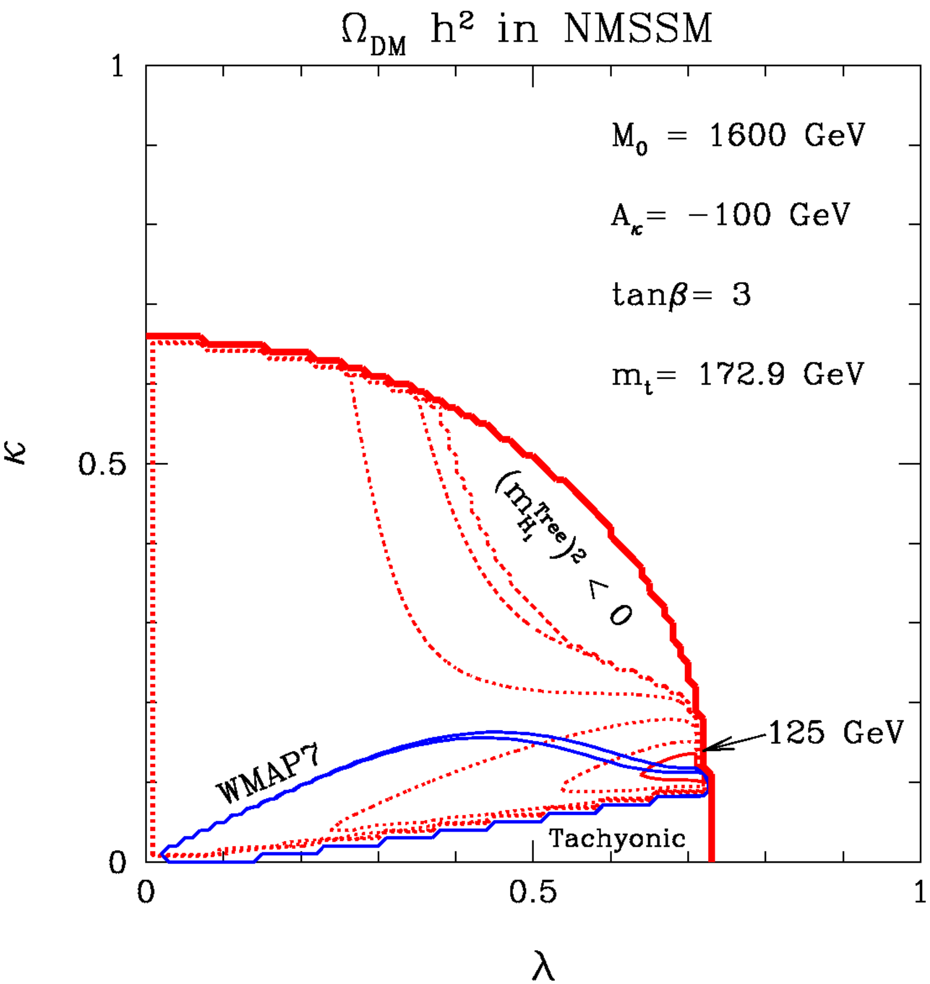


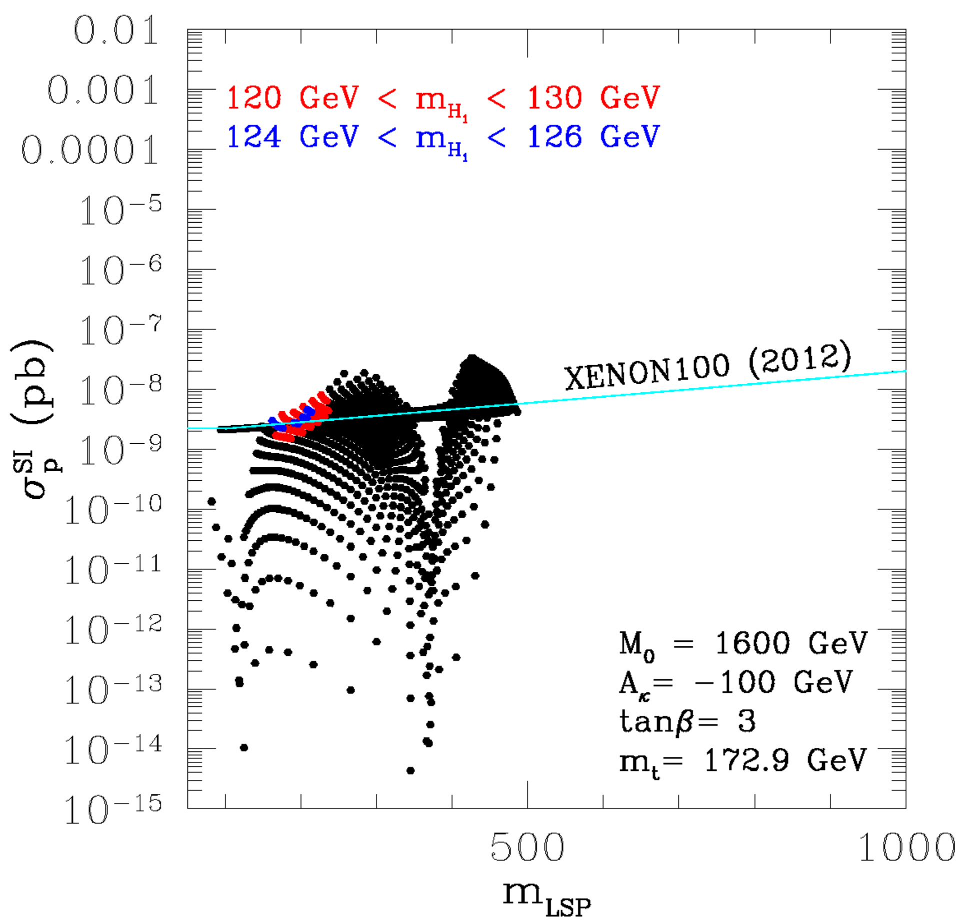


Small mixing is required to achieve $m_{h_2} = 125$ GeV

Relaxed for larger M_0

Dark Matter





Caveat: up to moduli problem