A little more gauge mediation and light Higgs mass

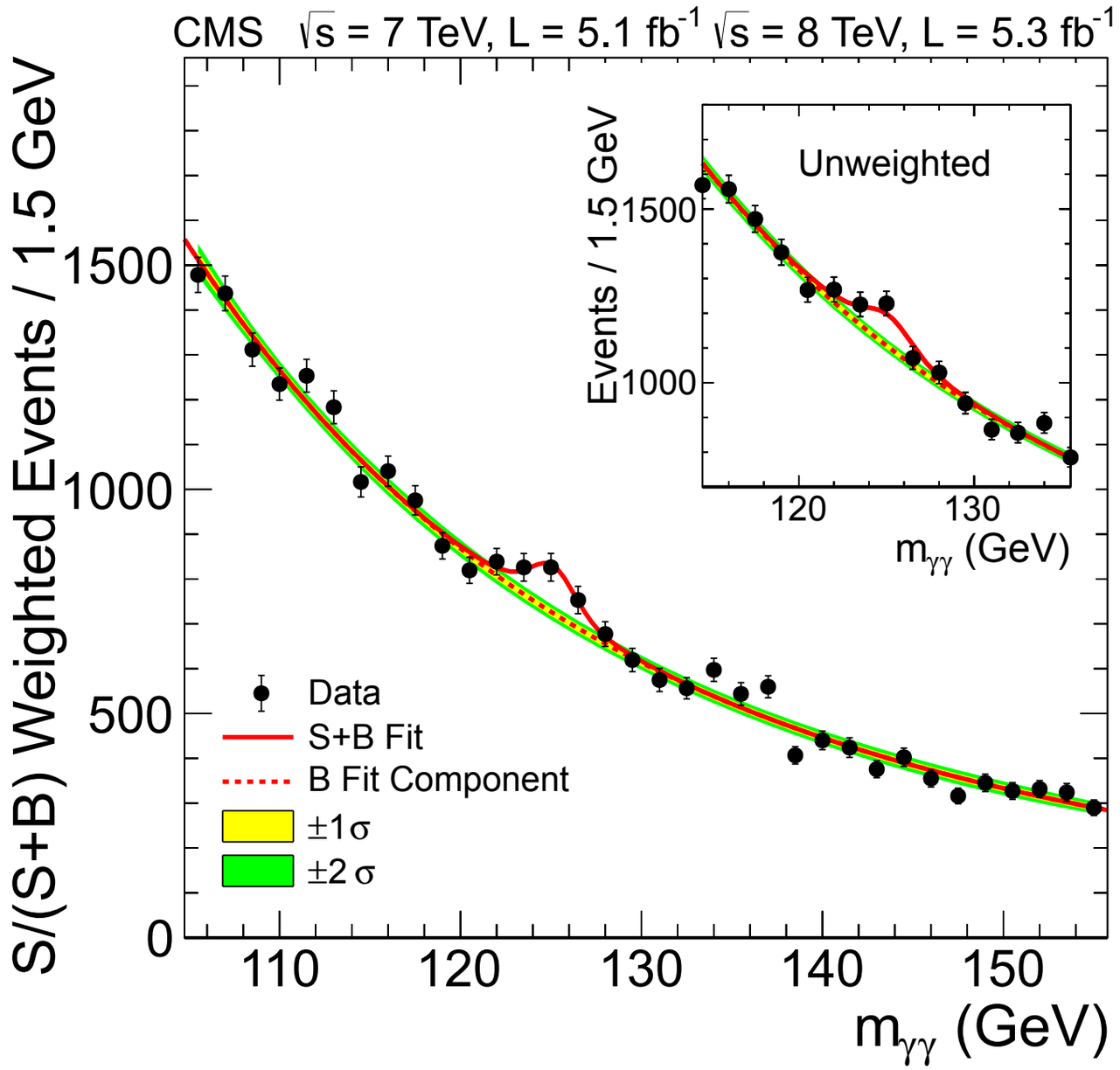
PLANCK 2014, Paris

May 2014

Sudhir Vempati

Centre for High Energy Physics
Indian Institute of Science
Bangalore

The Higgs bump at LHC



Speed breakers to Zero Stop mixing ??

Upper bound on Light Higgs (one loop)

$$m_t(m_{SUSY}) \approx 157 \ \ \text{GeV}$$

$$m_h^2 = m_Z^2 \cos^2 2\beta + \Delta m_h^2$$

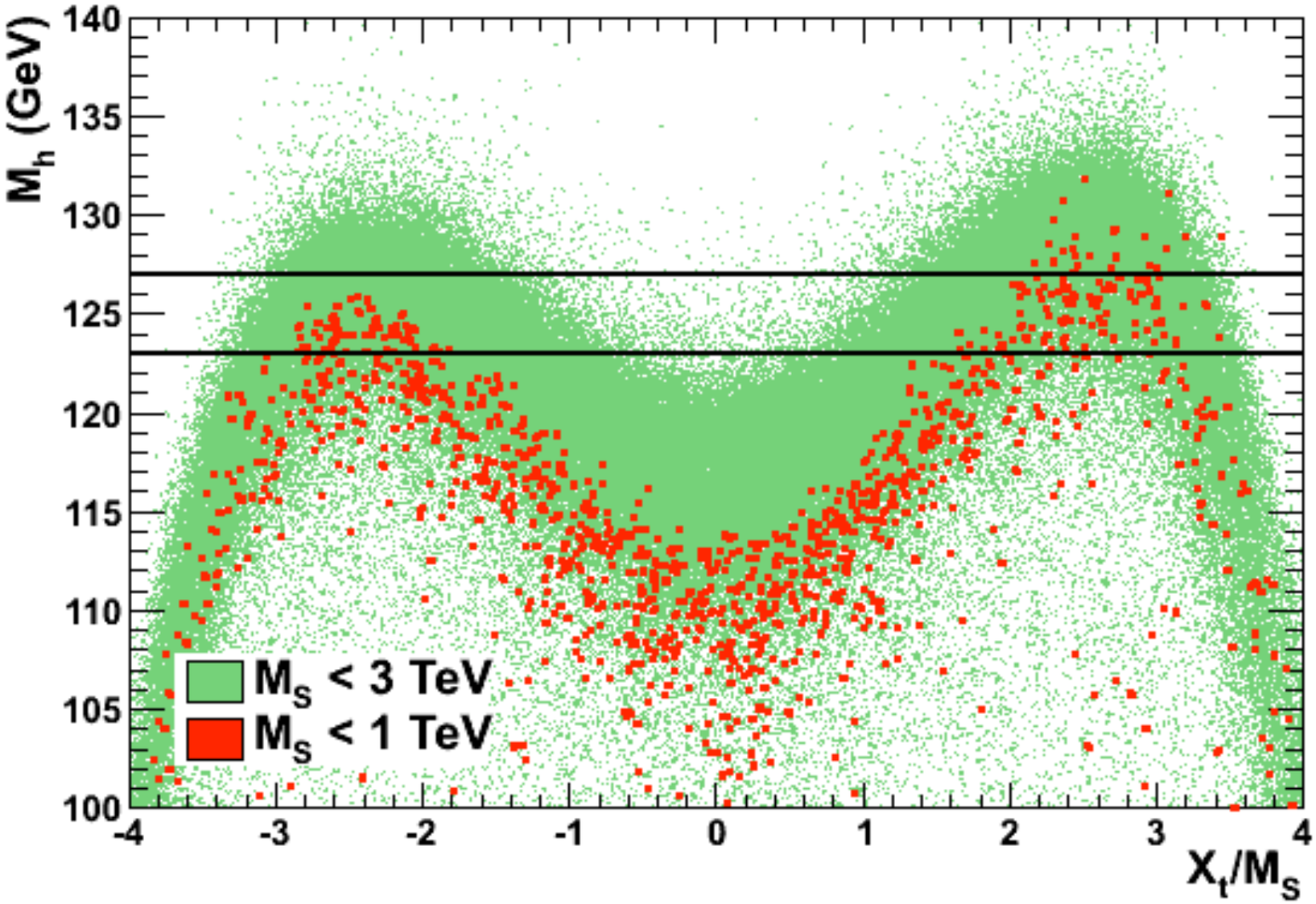
$$\Delta m_h^2 \simeq \frac{3 g_2^2 m_t^4}{8\pi^2 M_W^2} \left[\log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \right) + \frac{X_t^2}{m_{\tilde{t}_1} m_{\tilde{t}_2}} \left(1 - \frac{X_t^2}{12 m_{\tilde{t}_1} m_{\tilde{t}_2}} \right) \right]$$

for m_{SUSY} = 1 TeV, we have an upper bound of 135 GeV

pretty robust prediction.

Fixed Order

phenomenological models



Abrey et al.
1112.3028;
2012 updates

For zero mixing, we need multi TeV Stops !!!

Other option is to have maximal mixing : $|X_t| \sim \sqrt{6} M_S$

Theorem

- If LHC discovers light stops (less than TeV) and they are strongly mixed: then MSSM structure is true.

- If LHC discovers light stops and they have zero mixing, it points to structures beyond MSSM (like NMSSM , D-terms etc..)

Minimal Gauge Mediation

No SUSY flavour violation

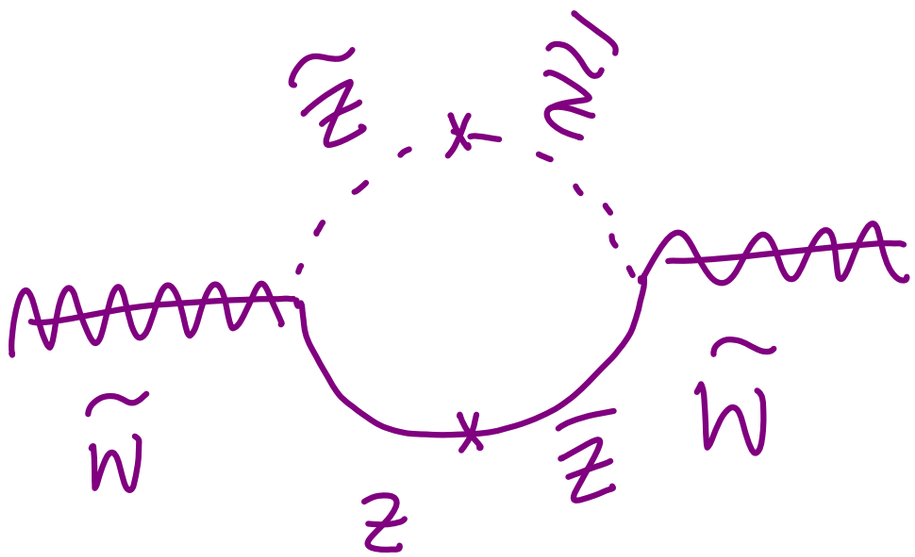
small number of parameters

$$W = \lambda \Phi \bar{\Phi} X$$

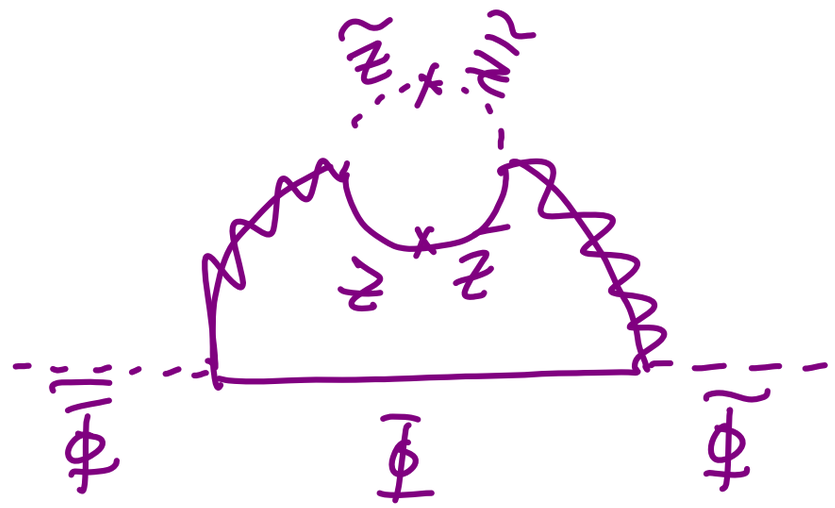
messengers (charged under SM)

SUSY breaking spurion

SUSY broken spontaneously by X

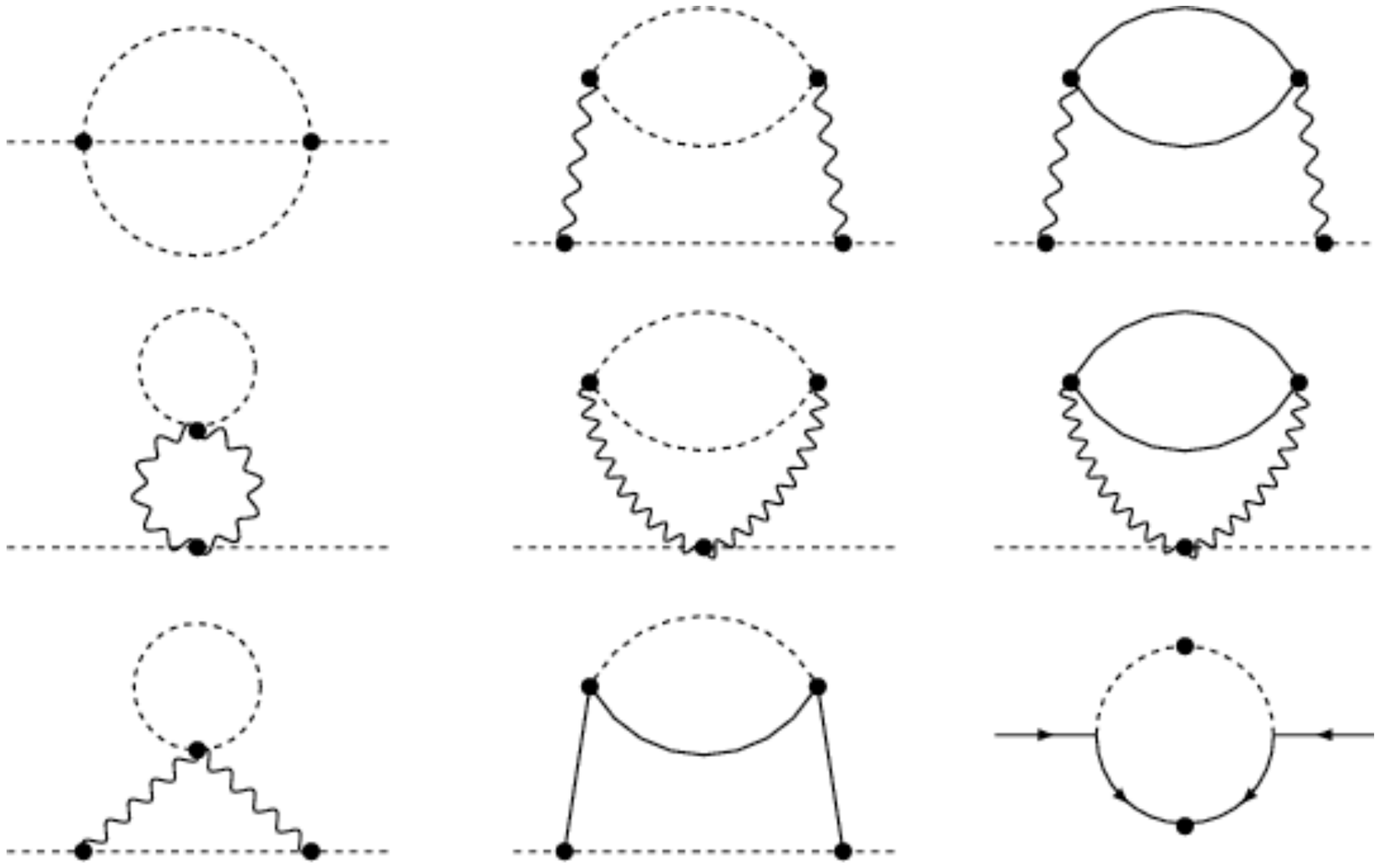


Soft masses in MSSM through loops

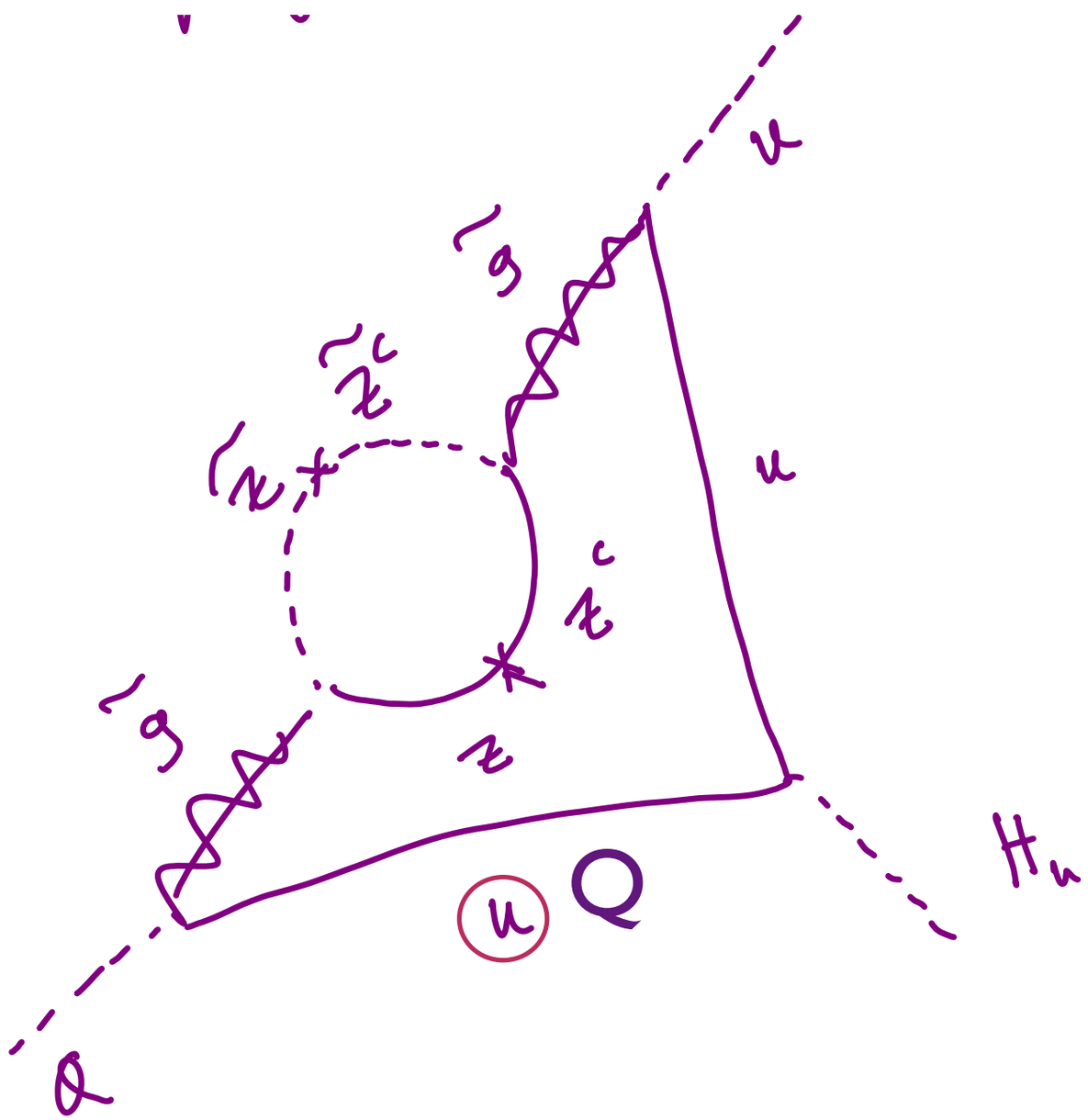


+ - - bunch of two loop diagrams

Two loop diagrams contributing to soft masses



Trilinear Couplings



additional coupling suppression

A-terms are essentially zero !!!

Draper, Meade, Shih et.al 1112.3068

Gauge Mediation and light higgs mass

the A-terms in the gauge mediation are very small !!

So a 125 GeV Higgs is very difficult unless we have a very heavy stop spectrum (beyond LHC)

Draper, Meade, Shih et.al 1112.3068

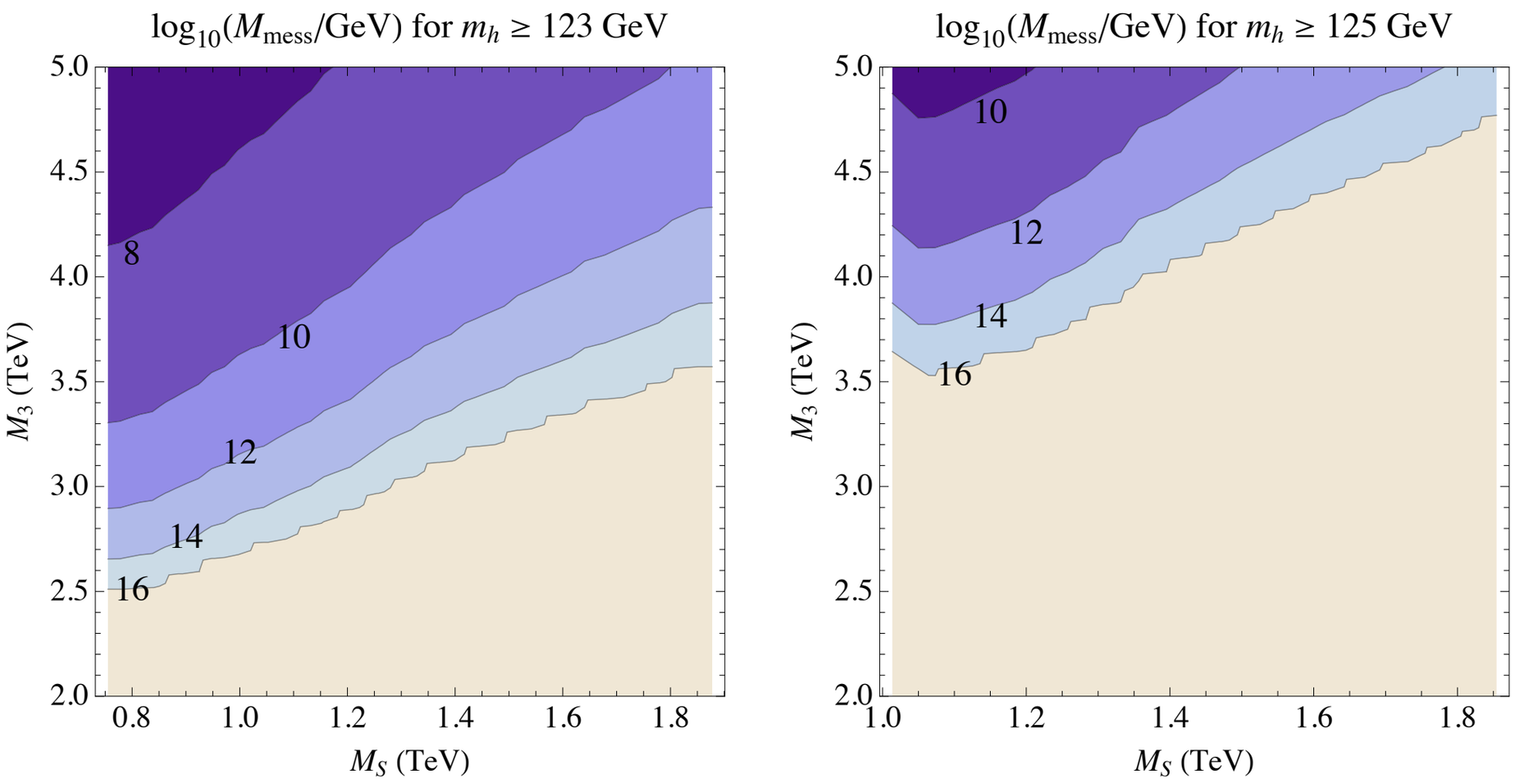


FIG. 5. Messenger scale required to produce sufficiently large $|A_t|$ for $m_h = 123$ GeV (left) and $m_h = 125$ GeV (right) through renormalization group evolution.

The change required in the messenger scale is a bit too large : almost up to GUT scale

$$A_t(M_{\rm SUSY}) \approx \frac{1}{16\pi^2} 10^{(-5)} \Lambda_G \; Log(\frac{M_X}{M_{\rm SUSY}})$$

Ways out for Gauge Mediation

(1) Have *Yukawa* mediation in addition to gauge mediation. This can be achieved by having matter-messenger fields mixing.

flavour violation !!!!

Delgado, Giudice, Rattazzi et. al, Yanagida et.al, Babu et. al, Shadmi et.al, Calibbi et. al,

review: Shih et.al, 1303.0228

(2) Have additional matter in the higgs sector.

some amount of Messenger-Matter mixing !

Langacker et. al, Yanagida et. al

(3) Additional strongly coupled sectors

Yanagida et. al

Our solutions

Say NO to messenger-Matter mixing !!!

(1) Little extra gauge mediation (with a singlet)

V. S. Mummidi and S Vempati, 1311.4280 (Nucl. Phy.s B)

(2) Add Neutrinos and impose Supersymmetric Inverse Seesaw Mechanism

E. J. Chun, V. S. Mummidi and S Vempati, 1405.5478

(3) Gravitational Rescue of Minimal Gauge Mediation

A. Iyer, V. S. Mummidi and S Vempati, to appear

A little more gauge mediation

Add an additional U(1) to regular SM gauge group mediation

Add a singlet !!

(Remember NMSSM does not work in Minimal Gauge Mediation)

de Gouvea, Friedland , Murayama
Dine, Nir, Shirman

In NMSSM

$$v_s \approx -\frac{1}{4\kappa}\left(-A_\kappa - \sqrt{-A_\kappa - 8m_s^2}\right)$$

extremely small in ordinary GMSB

In U(1) extended NMSSM:

$$W = W_{\rm MSSM} + \lambda S H_u H_d$$

$$v_s^2 \approx \frac{2m_s^2}{s^2 g_4^2}$$

Similar to many U(1) extended models.

Anomalies !!

$$\mathcal{A}_1 \ : \ U(1)_A - [SU(3)_C]^2$$

$$\mathcal{A}_2 \ : \ U(1)_A - [SU(2)_L]^2$$

$$\mathcal{A}_3 \ : \ U(1)_A - [U(1)_Y]^2$$

$$\mathcal{A}_4 \ : \ U(1)_Y - [U(1)_A]^2$$

$$\mathcal{A}_5 \ : \ U(1)_A^3$$

Minimal Matter content required to cancel the anomalies

$$W = W_{\rm MSSM} + \lambda S H_u H_d + \kappa_i S D_i \bar{D}_i$$

three pairs of coloured triplets

$$G^2 = g_1^2 + g_2^2$$

The Higgs mass

$$\begin{aligned}
\left(\mathcal{M}_+^0\right)_{11}^2 &= \left[\frac{G^2}{4} + h_1^2 {g_4}^2\right] v_1^2 + \frac{A_\lambda}{\sqrt{2}} \frac{v_2 v_s}{v_1} \\
\left(\mathcal{M}_+^0\right)_{12}^2 &= -\left[\frac{G^2}{4} - \lambda^2 - h_1 h_2 {g_4}^2\right] v_1 v_2 - \frac{A_\lambda}{\sqrt{2}} v_s \\
\left(\mathcal{M}_+^0\right)_{13}^2 &= \left[\lambda^2 + h_1 s {g_4}^2\right] v_1 v_s - \frac{A_\lambda}{\sqrt{2}} v_2 \\
\left(\mathcal{M}_+^0\right)_{22}^2 &= \left[\frac{G^2}{4} + h_2^2 {g_4}^2\right] v_2^2 + \frac{A_\lambda}{\sqrt{2}} \frac{v_1 v_s}{v_2} \\
\left(\mathcal{M}_+^0\right)_{23}^2 &= \left[\lambda^2 + h_2 s {g_4}^2\right] v_2 v_s - \frac{A_\lambda}{\sqrt{2}} v_1 \\
\left(\mathcal{M}_+^0\right)_{33}^2 &= s^2 {g_4}^2 v_s^2 + \frac{A_\lambda}{\sqrt{2}} \frac{v_1 v_2}{v_s}
\end{aligned}$$

Tree level upper bound !

$$m_{h_0}{}^2 \leq M_Z^2 \left[\cos 2\beta^2 + \frac{\lambda^2}{2g^2} \sin 2\beta^2 + \frac{g_4^2}{g^2}(h_1 + h_2 + (h_1 - h_2)\cos 2\beta)^2\right]$$

One loop corrections to Higgs

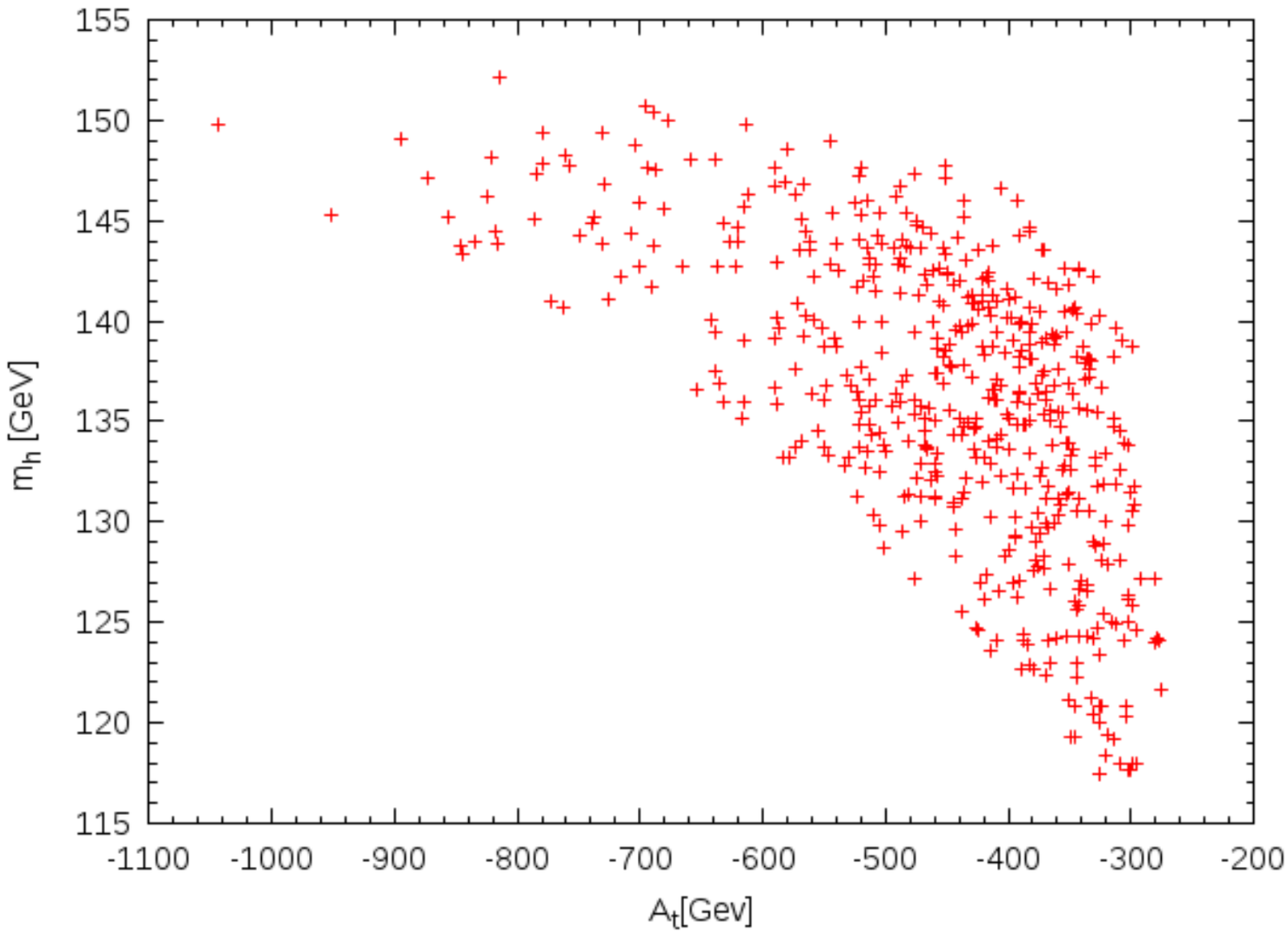
standard top /stop corrections

Exotic (Quark) corrections to the Higgs mass matrix

Considered Minimal Messenger Model with
five extra dimensionless couplings !!

Messenger scale is
taken twice that of
the \Lambda in this case

Parameter	Range
Λ	$1 \times 10^5 \ - \ 5 \times 10^7 [GeV]$
g_4	$0.01 - 2.5$
λ	$0.1 - 0.9$
κ_1	$0.1 - 0.9$
κ_2	$0.1 - 0.9$
κ_3	$0.1 - 0.9$



Sooryanarayana and Vempati, (Nucl Phys B) 884 2014

with constraints M_Z' searches etc., taken in to consideration

The RGE generated At is still small !! But the Higgs mass is the in right range !!

(neglected the vector contributions !)

Neutrinos can rescue Higgs

Chun, Sooryanarayana, Vempati, to appear

Consider supersymmetric Inverse Seesaw Mechanism

$$W = W_{\rm MSSM} + Y_N L H_u N^c + M_R N^c S + \mu_S S S$$

$$m_\nu = \frac{m_D^2 \mu_S}{M_R^2}$$

This coupling can be large !!! (Mass is called m_D)

$$m_D \lesssim 0.05 M_R$$

From Electroweak precision tests

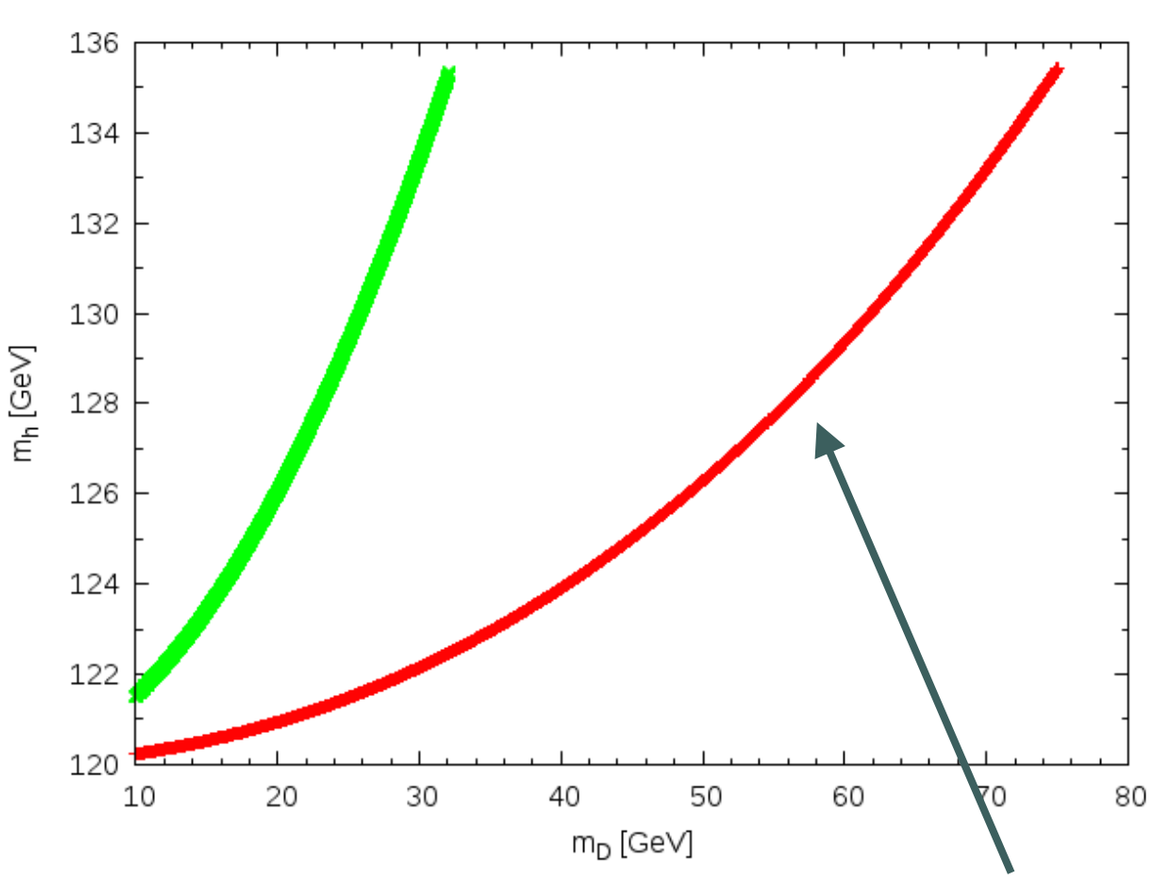
Perez-Victoria et. al

Neutrinos can rescue Higgs

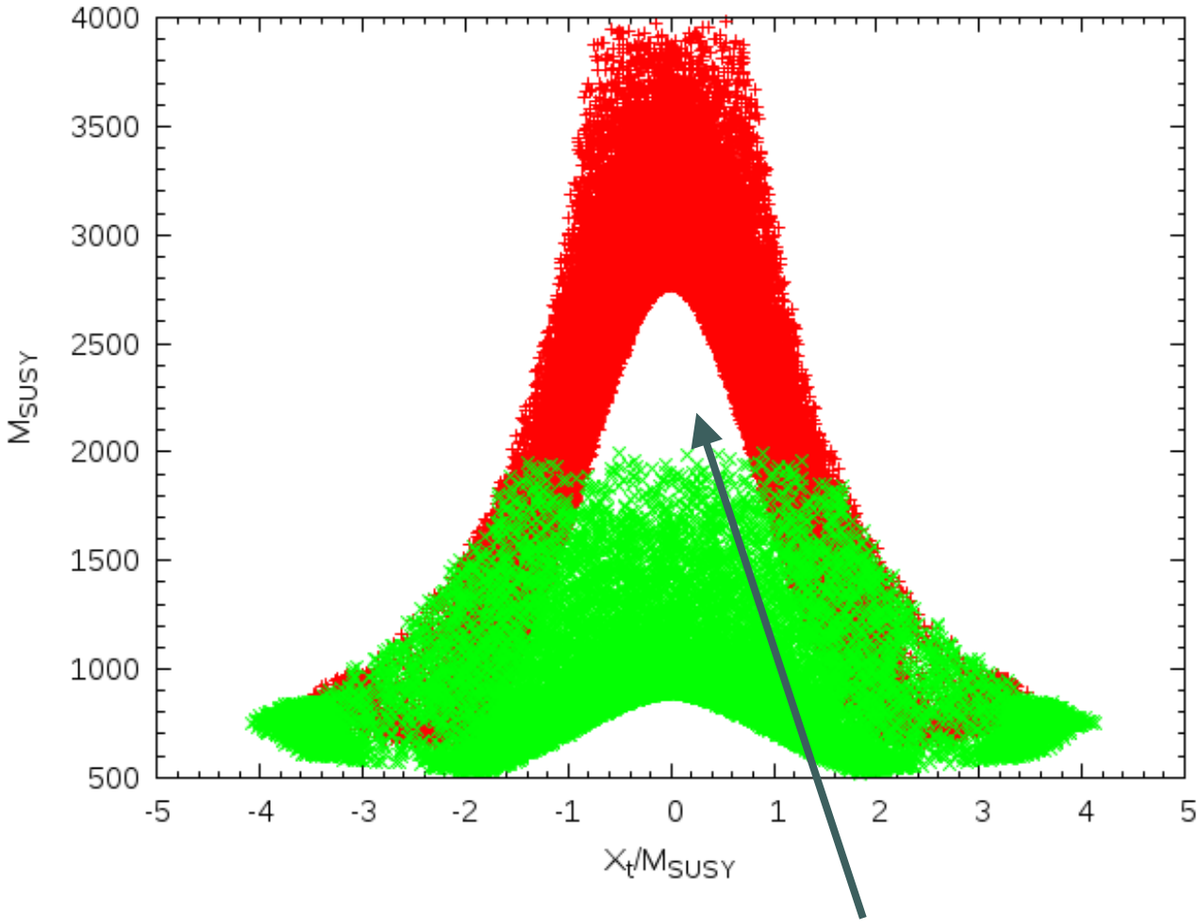
Chun, Sooryanarayana, Vempati, to appear

Complete 1-loop effective potential corrections including neutrino sector for a general susy breaking sector

Guo et. al
Shafi et. al



with mixing X_N



GMSB Region

Summary

126 GeV Higgs is compatible with TeV scale MSSM !!!
Perhaps it is just around the corner.

But, at the same time, the discovery of Higgs has put severe constraints on known Supersymmetric models even more than direct constraints !!

Of the models minimal gauge mediation models are the most constrained. But, simple ways can be found without introducing messenger-matter mixing.

For example, we have shown a simple extra U(1) or neutrino couplings can give you the required enhancement without generating large A_t