An Overview of SUSY Models for the Higgs Mass

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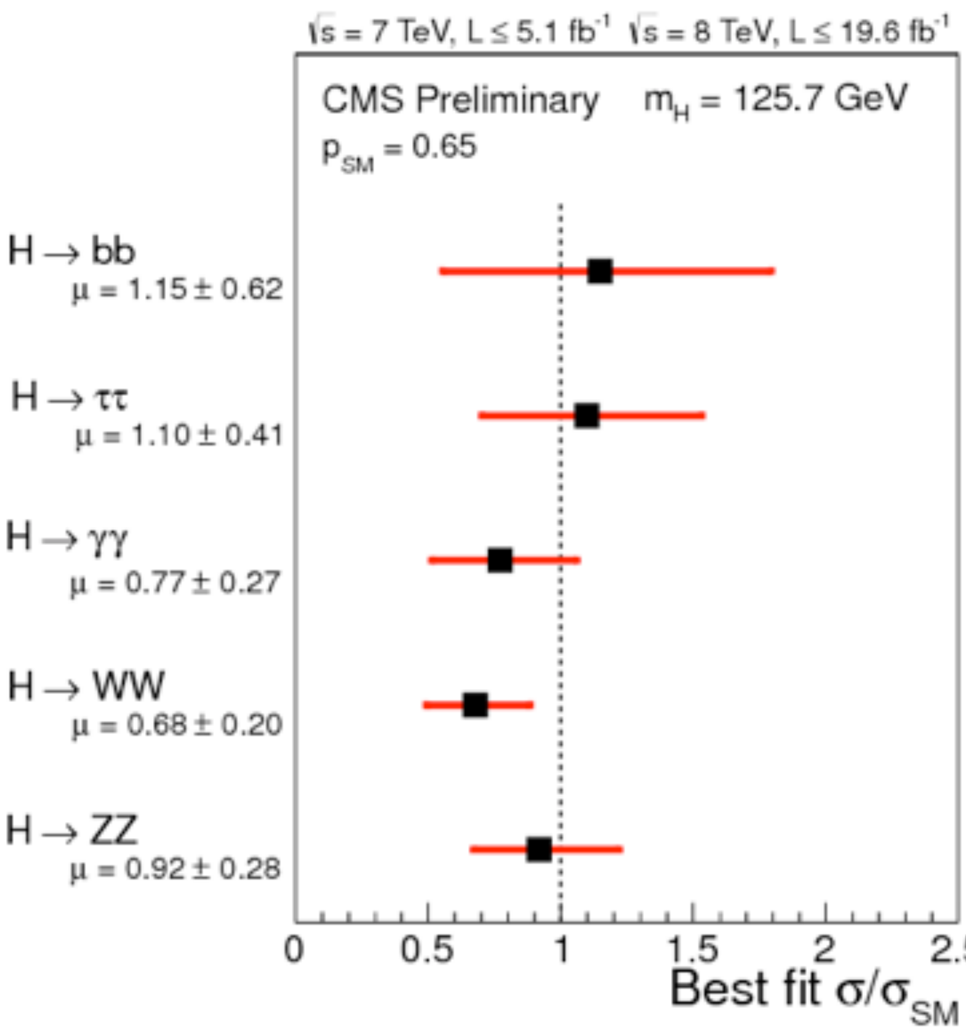
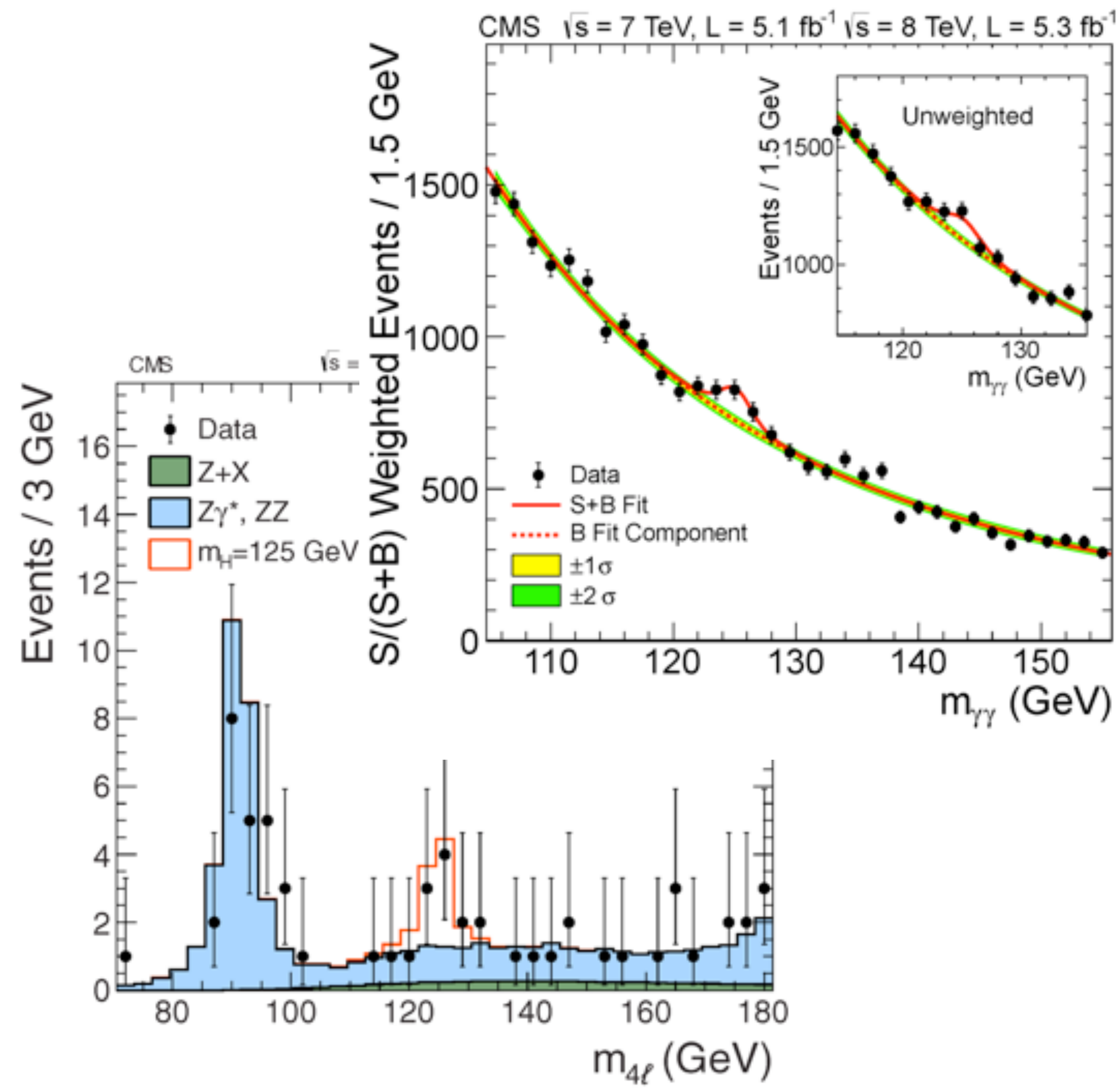
Draper, Meade, Reece & DS (1112.3068)
Craig, Knapen, DS & Zhao (1206.4086)
Craig, Knapen & DS (1302.2642)
Evans & DS (1303.0228)

The Higgs recently turned one year old

Happy Birthday Higgs!

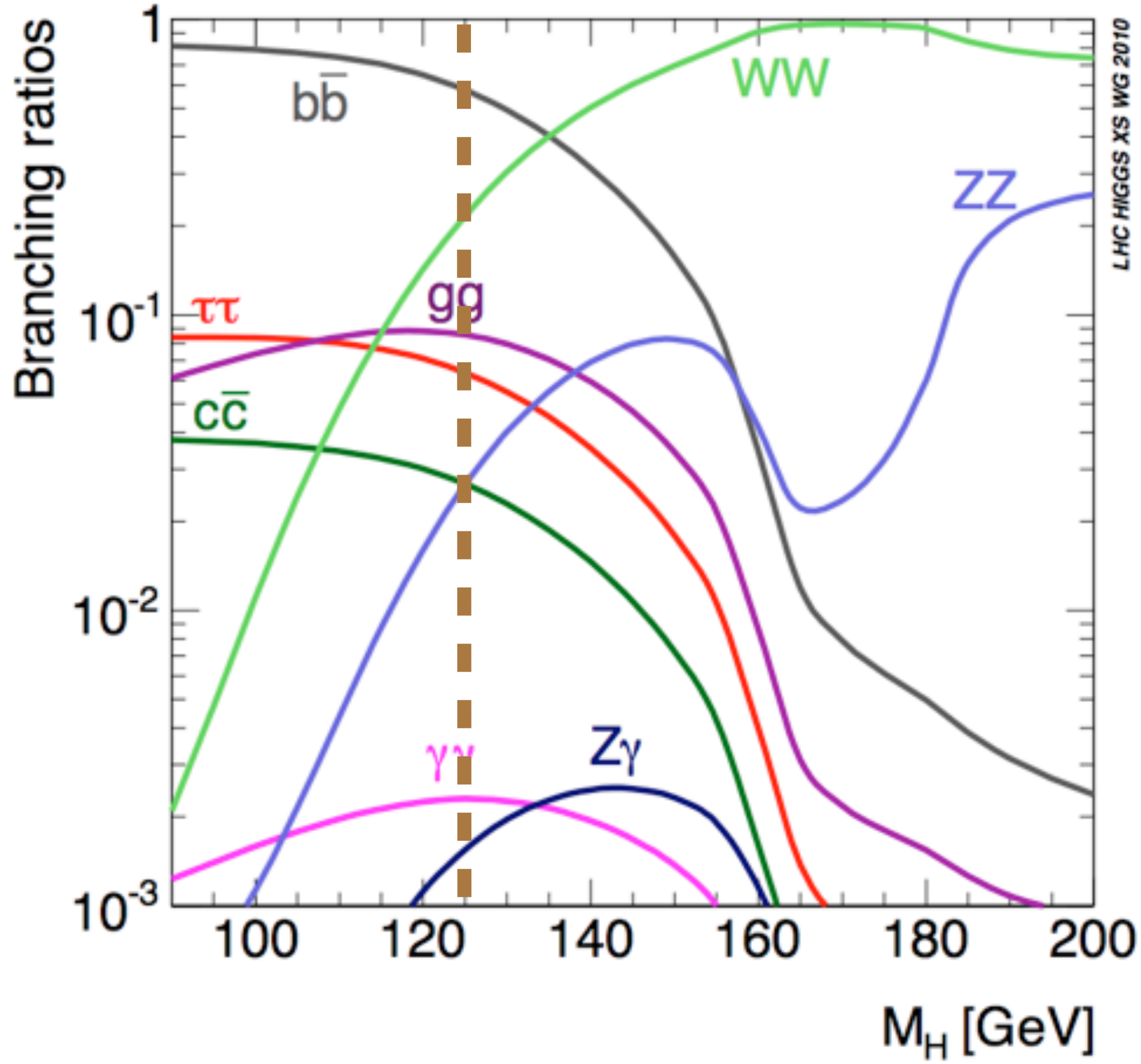
In the past year we have learned a lot about the properties of the Higgs...





Indeed, a Higgs mass of 125 GeV is a dream-come-true for experimentalists.

Nearly all of its decay modes are accessible at the LHC.



But for theorists, the Higgs at 125 GeV continues to haunt our dreams.

Why did Nature choose this value?? Is the EW scale natural or fine tuned??

Higgs Mass in the MSSM

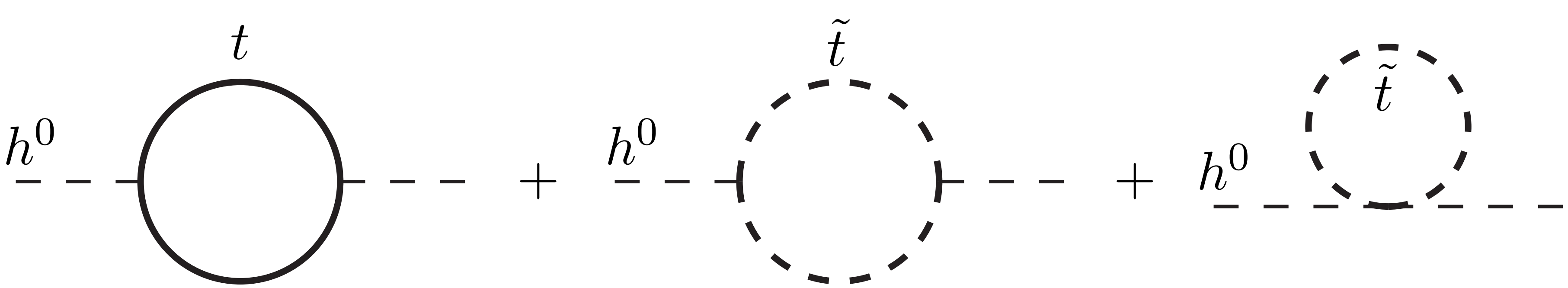
- In the MSSM, the Higgs mass is constrained to be less than mZ at tree-level, because the quartic is tied to the gauge couplings.
- This is easiest to see in the decoupling limit:

$$V_{higgs} \approx -m^2|h|^2 + \frac{1}{2}\lambda|h|^4$$

$$m_h^2 = \lambda v^2 = (g^2 + g'^2)v^2 \cos^2 2\beta$$

- So we need loop corrections to lift the Higgs to 125 GeV.

$\Delta(m_{h^0}^2) =$



Higgs Mass in the MSSM

- In more detail

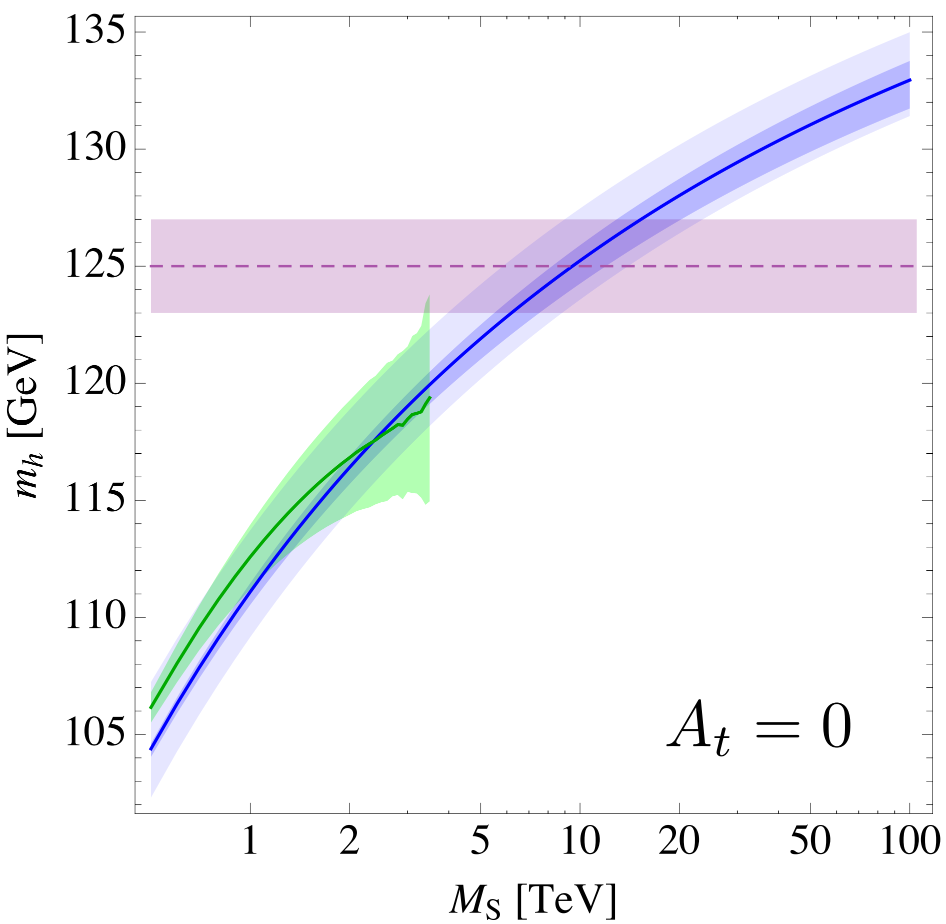
$$(\delta m_h^2)_{1-loop} = \frac{3m_t^4}{4\pi^2 v^2}\left(\log\left(\frac{M_S^2}{m_t^2}\right) + \frac{A_t^2}{M_S^2}\left(1 - \frac{A_t^2}{12M_S^2}\right)\right)$$

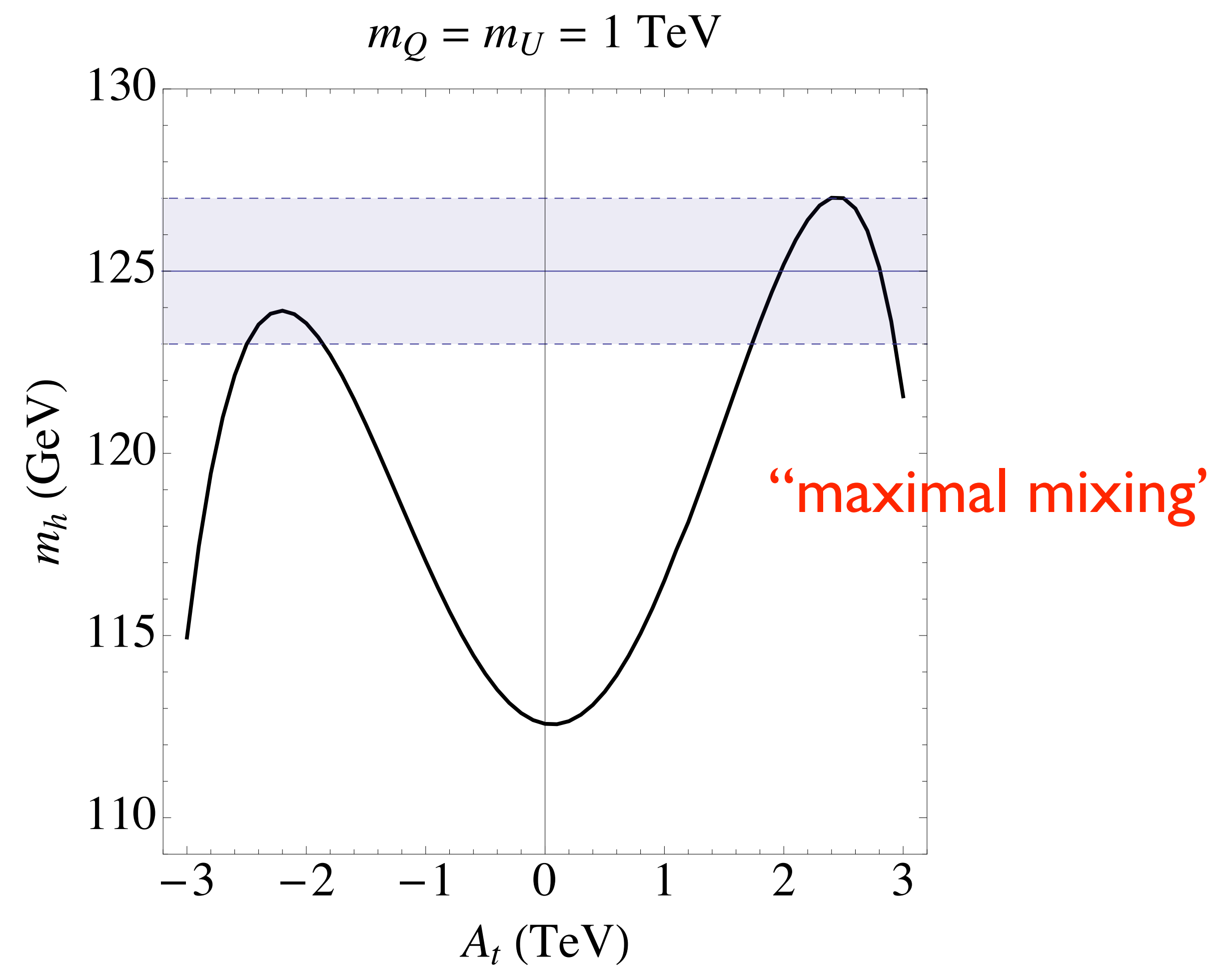
- Here the "A-term" A_t is responsible for mixing the two stops, and M_S is the SUSY scale set by the stop masses:

$$m_{\tilde{t}}^2 = \begin{pmatrix} m_{Q_3}^2 & A_t v_u \\ A_t^* v_u & m_{U_3}^2 \end{pmatrix}, \qquad M_S^2 \equiv m_{\tilde{t}_1} m_{\tilde{t}_2}$$

- So there are two ways to lift the Higgs mass in the MSSM:
  - raise the stop masses
  - dial A_t to maximize the second term.

Higgs Mass in the MSSM

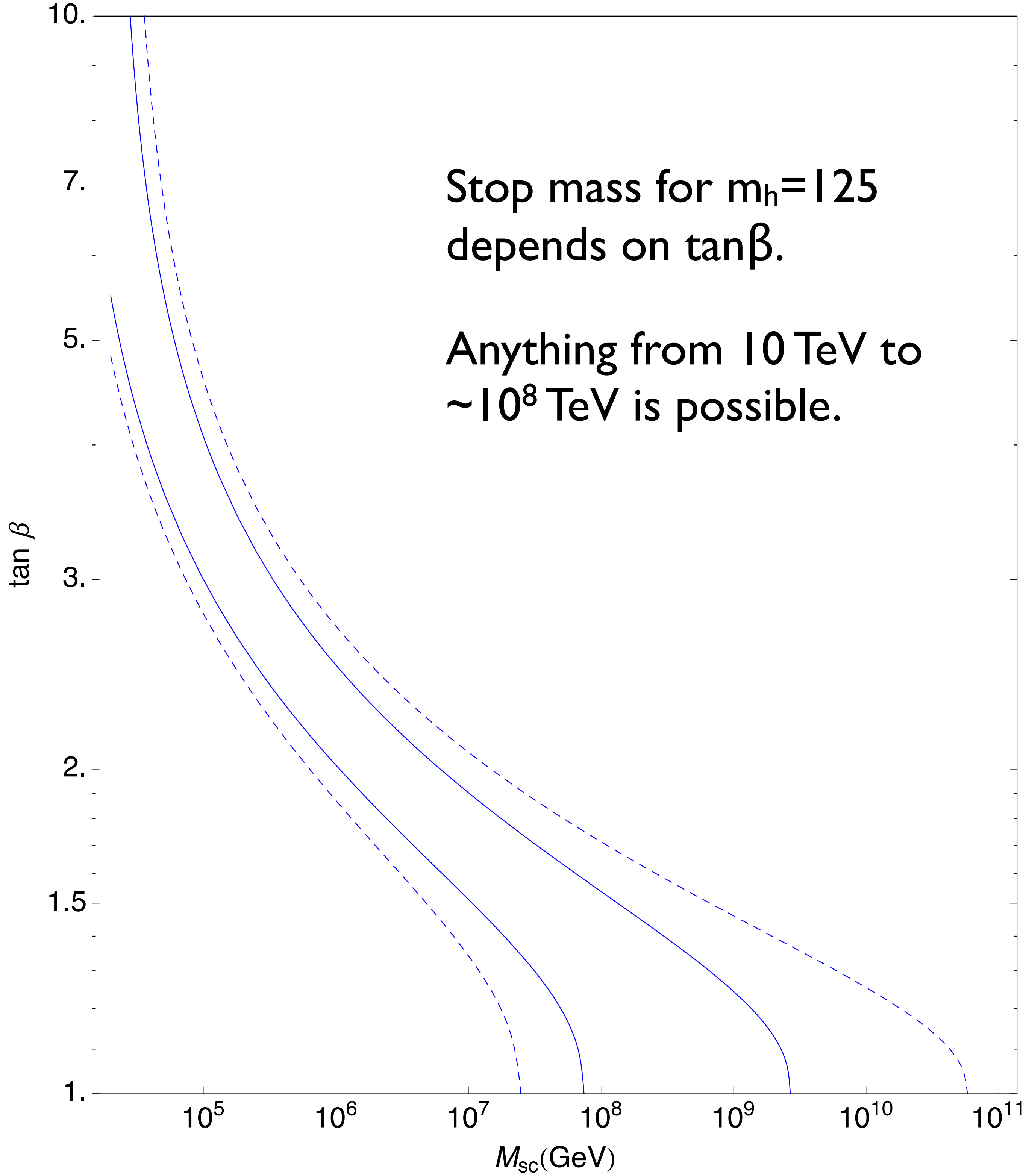




Draper, Meade, Reece & DS

Need $M_S \gtrsim 10$ TeV or $A_t \sim \sqrt{6}\ M_S$ to achieve 125 GeV.

Very Heavy Stops



Stop mass for m_h=125 depends on tanβ.

Anything from 10 TeV to ~10^8 TeV is possible.

- "Mini-split SUSY"
- Highly unnatural EW tuning but simplicity in "model space"
- 100-1000 TeV stops motivated by anomaly mediation, flavor problem, R-symmetry
- Can accommodate unification, dark matter.

Bhattacherjee, Feldstein, Ibe, Matsumoto, Yanagida

Arvanitaki, Craig, Dimopoulous, Villadoro

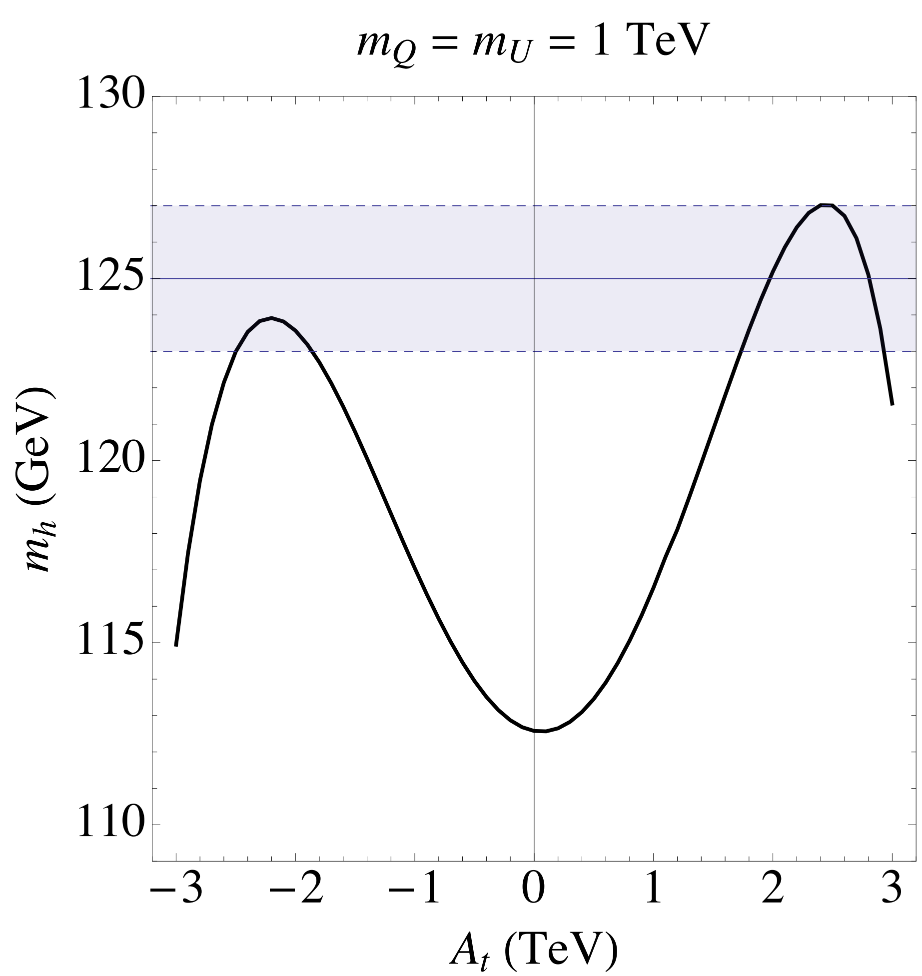
Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski

Draper, Meade, Reece, DS
Craig, Knapen, DS, Zhao
Craig, Knapen, DS
Evans & DS

Large A-terms

Evans, Ibe, Shirai, Yanagida
Kang, Li, Liu, Tong, Yang
Abdullah, Galon, Shadmi, Shirman
....

Large A-terms allow for TeV-scale stops. Fine tuning is greatly reduced. Here the challenge is to generate the A-terms from a UV model.



- The A-terms are trilinear soft-SUSY breaking couplings

$$\mathcal{L}_{soft} \supset A^u_{ij} Q_i U_j H_u + A^d_{ij} Q_i D_j H_d + A^\ell_{ij} L_i E_j H_d$$

$$A_t \equiv A^u_{33}$$

- How to generate large A-terms in a flavor-blind way? Gauge mediation does not do it...

- We will return to this shortly...

Beyond the MSSM

- Add new states to the MSSM which couple to Higgs with O(1) strength and break SUSY => new contributions to Higgs quartic
- Generally, the focus is on tree-level, since otherwise we're not doing better than the MSSM.
  - See however the many works on extra vector-like generations.
- Two options:
  - "non-decoupling F-terms": new states couple to the Higgs via the superpotential
  - "non-decoupling D-terms": new states couple to the Higgs via the gauge potential

Non-decoupling F-terms

- The NMSSM is a prime example of non-decoupling F-terms:

$$W = \lambda S H_u H_d \qquad \delta V_h \sim |\frac{\partial W}{\partial S}|^2 \sim \lambda^2 v^4 \sin^2 2\beta$$

$$\delta m_h^2 \sim \lambda^2 v^2 \sin^2 2\beta$$

- Well-known problems with fundamental singlets...

- No Landau pole for λ => another upper bound on tree-level Higgs mass. Only a slight improvement over the MSSM tuning.

- Relaxing Landau pole constraint => motivated by Seiberg duality? aka "λ-SUSY", aka "Fat Higgs"

Barbieri, Hall, Nomura, Rychkov
Harnik, Kribs, Larson, Murayama
...
Hall, Pinner, Ruderman



Batra, Delgado, Kaplan & Tait '03

Non-decoupling D-terms

- The basic idea: charge the Higgs under additional gauge group. When this gauge symmetry is broken non-supersymmetrically, an additional D-term potential for the Higgs is generated.

- A simple $U(1)_x$ toy model: (H_u, H_d, Φ_+, Φ_-) charges (+1,-1,+1,-1)

$$W = S(\phi_+\phi_- - w^2) \qquad V_{soft} = m^2(|\phi_+|^2 + |\phi_-|^2)$$

$$\delta V_D = g_x^2(|H_u|^2 - |H_d|^2 + |\phi_+|^2 - |\phi_-|^2)^2$$

- In the presence of V_{soft}, the Higgs quartic gets a new term:

$$\delta V_h = g_x^2 \left(1 + \frac{2m_x^2}{m^2}\right)^{-1} (|H_u|^2 - |H_d|^2)^2$$

Non-decoupling D-terms

- Models with nonabelian groups (e.g. SU(2)) were also constructed
- Gauge coupling unification is nontrivial, but can be accommodated with enough complications (Batra, Delgado, Kaplan & Tait; Maloney, Pierce & Wacker; ...)
- Fine tuning ameliorated but not eliminated -- scales like $1/m_X^2$. For max 10% tuning consistent with EWPT and direct searches, must have m_X~3-10 TeV (Maloney, Pierce & Wacker)
- These models generically predict enhanced coupling to bb. Could be observable at LHC/ILC, but not necessarily. (Blum, D'Agnolo, Fan; Azatov, Chang, Craig, Galloway)

More on models for A-terms

Overview of the strategies

$$\mathcal{L}_{soft} \supset A^u_{ij} Q_i U_j H_u + A^d_{ij} Q_i D_j H_d + A^\ell_{ij} L_i E_j H_d$$

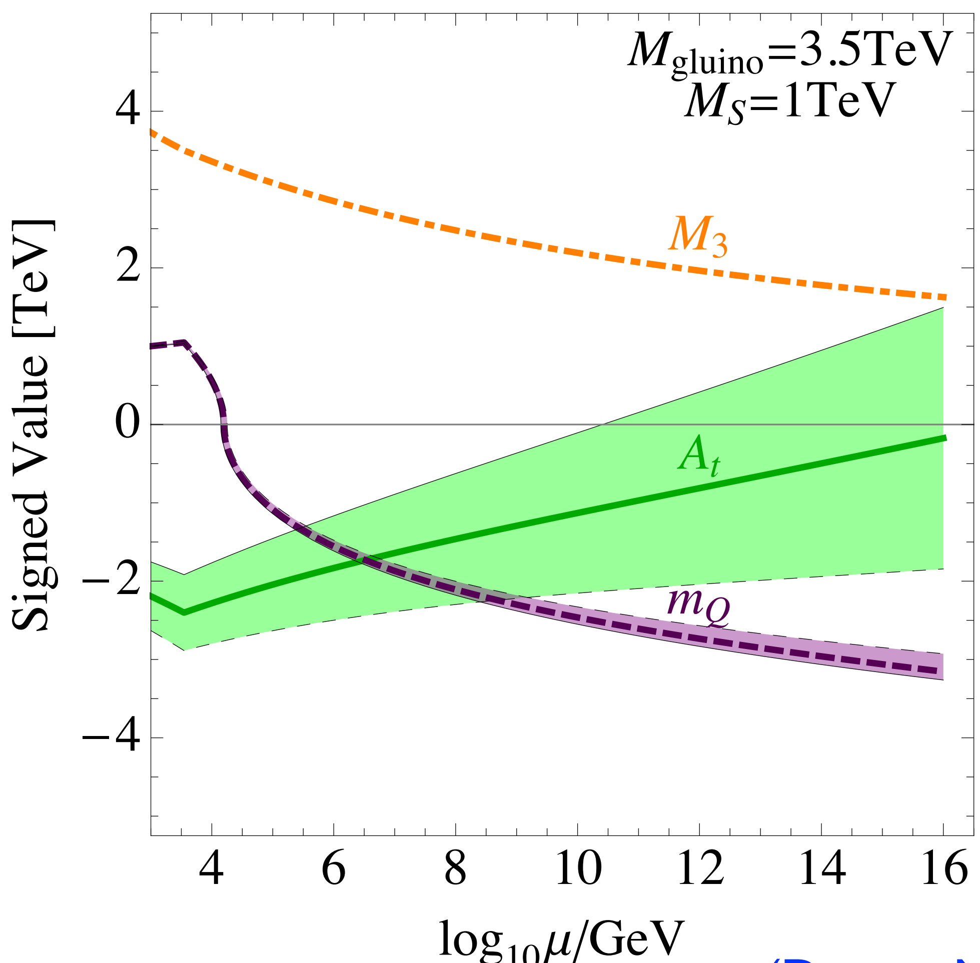
- A-terms from MSSM RGs
  - The only option for pure gauge mediation models
- A-terms at the messenger scale
  - Requires direct messenger-MSSM interactions
  - Weakly-coupled models
  - Strongly-coupled models

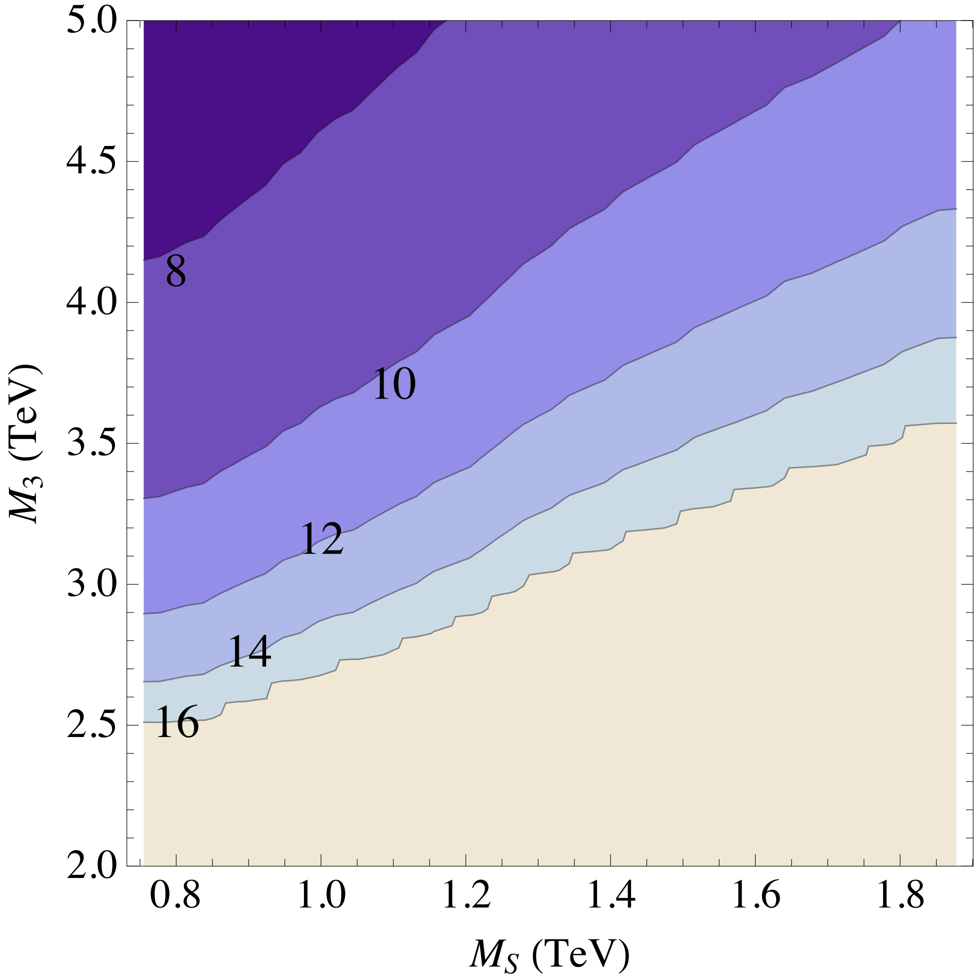
A-terms have been rather neglected in the past. Not at all a well-studied area. Interesting opportunities await!

A-terms through RG

$$16\pi^2 \frac{dA_t}{dt} \approx 12 y_t^2 A_t + \frac{32}{3} g_3^2 M_3$$

- Large weak-scale A-terms can arise through the RG.
- This is a highly constrained scenario. Requires $M_3 \gtrsim 3$ TeV and $M_{mess} \gtrsim 10^8$ GeV.

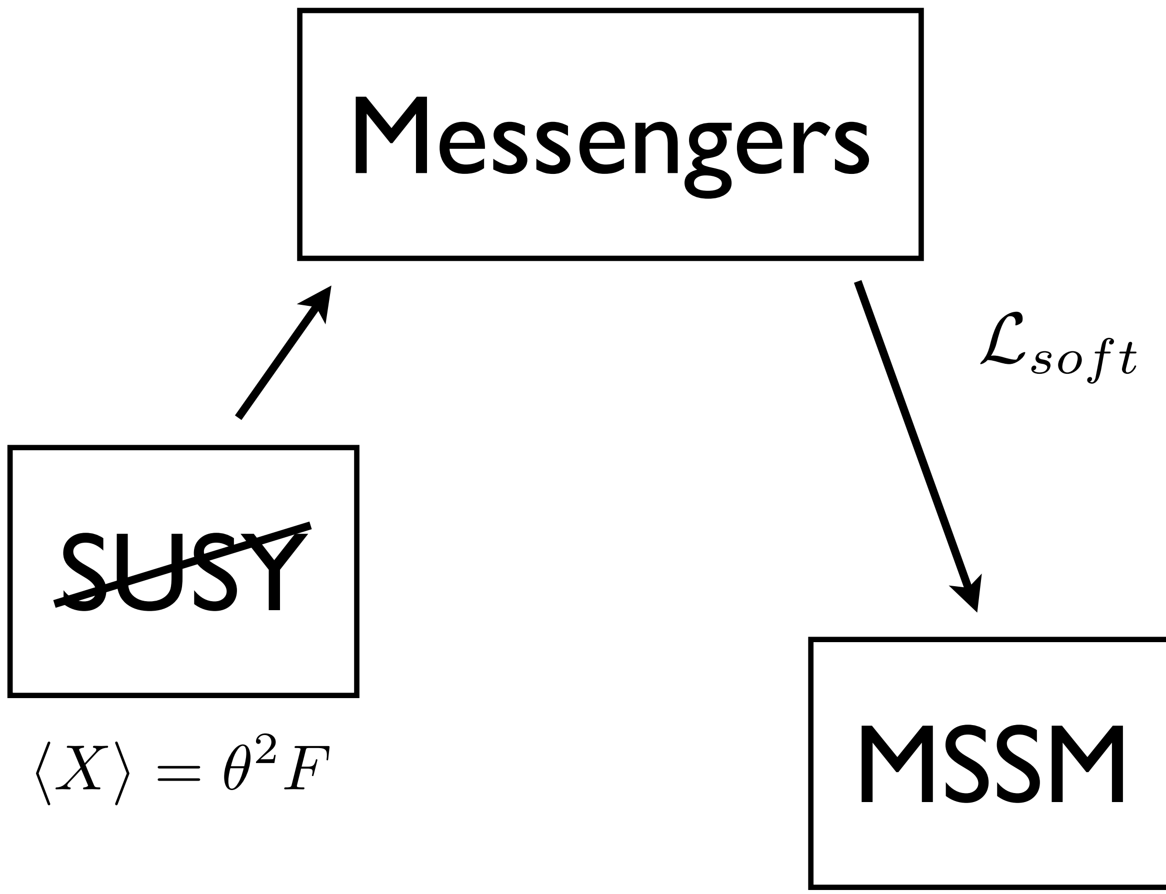




(Draper, Meade, Reece, DS)

A-terms through Messengers

- A-terms can also arise through integrating out the messengers of SUSY-breaking.



$$\langle X \rangle = \theta^2 F$$

$$\mathcal{L}_{soft} = \int d^4\theta \frac{X^\dagger X}{M^2} Q^\dagger Q + \ldots$$
$$= m_Q^2 Q^\dagger Q + \ldots$$

- Gauge interactions not enough! Need direct MSSM-messenger couplings.

Effective operators for A-terms

- The A-terms originate from the following effective operators:

$$\mathcal{L} \supset \int d^4\theta \, \frac{1}{M} \left(c_{Qij} X Q_i^\dagger Q_j + c_{Uij} X U_i^\dagger U_j + c_{H_u} X H_u^\dagger H_u \right)$$

  - Substitute SUSY-breaking spurion $\langle X \rangle = \theta^2 F$
  - Integrate over superspace $Q_i^\dagger \to F_{Q_i}^\dagger, \ \text{etc}$
  - Use Yukawa couplings

$$F_{Q_i}^\dagger = \partial_{Q_i} W_{MSSM} = \lambda_{ik}^u H_u U_k, \ \text{etc}$$

$$\mathcal{L} \supset A_{Qij} \lambda_{ik}^u H_u U_k Q_j + A_{Uij} \lambda_{ki}^u H_u Q_k U_j + A_{H_u} \lambda_{ij}^u H_u Q_i U_j$$

- Note:
  - The Higgs-type A-terms are automatically MFV (proportional to the Yukawas)
  - The squark-type A-terms are not automatically MFV

An obstacle to large A-terms

- Problem: the effective operators for A-terms and for mass-squareds are very similar.

$$c_{A_Q} \int d^4\theta \, \frac{X}{M} Q^\dagger Q \qquad \text{vs.} \qquad c_{m_Q^2} \int d^4\theta \, \frac{X^\dagger X}{M^2} Q^\dagger Q$$

- So they tend to be generated at the same loop order:

$$c_{A_Q} \sim c_{m_Q^2} \sim \frac{\alpha}{4\pi} \quad \Rightarrow \quad \frac{m_Q^2}{A_Q^2} \sim \frac{4\pi}{\alpha} \gg 1$$

- This is disastrous!

"The A/m^2 problem"

(Craig, Knapen, DS & Zhao)

Analogy with μ/Bμ

- The A/m^2 problem is completely analogous to the more well-known μ/Bμ problem.
- The operators for μ and Bμ also only differ by one power of X:

$$c_\mu \int d^4\theta \, \frac{X^\dagger}{M} H_u H_d \qquad \text{vs.} \qquad c_{B\mu} \int d^4\theta \, \frac{X^\dagger X}{M^2} H_u H_d$$

- Before the Higgs was discovered at 125 GeV, we were not forced to confront the A/m^2 problem.
- Now it is on the same footing as the μ/Bμ problem!

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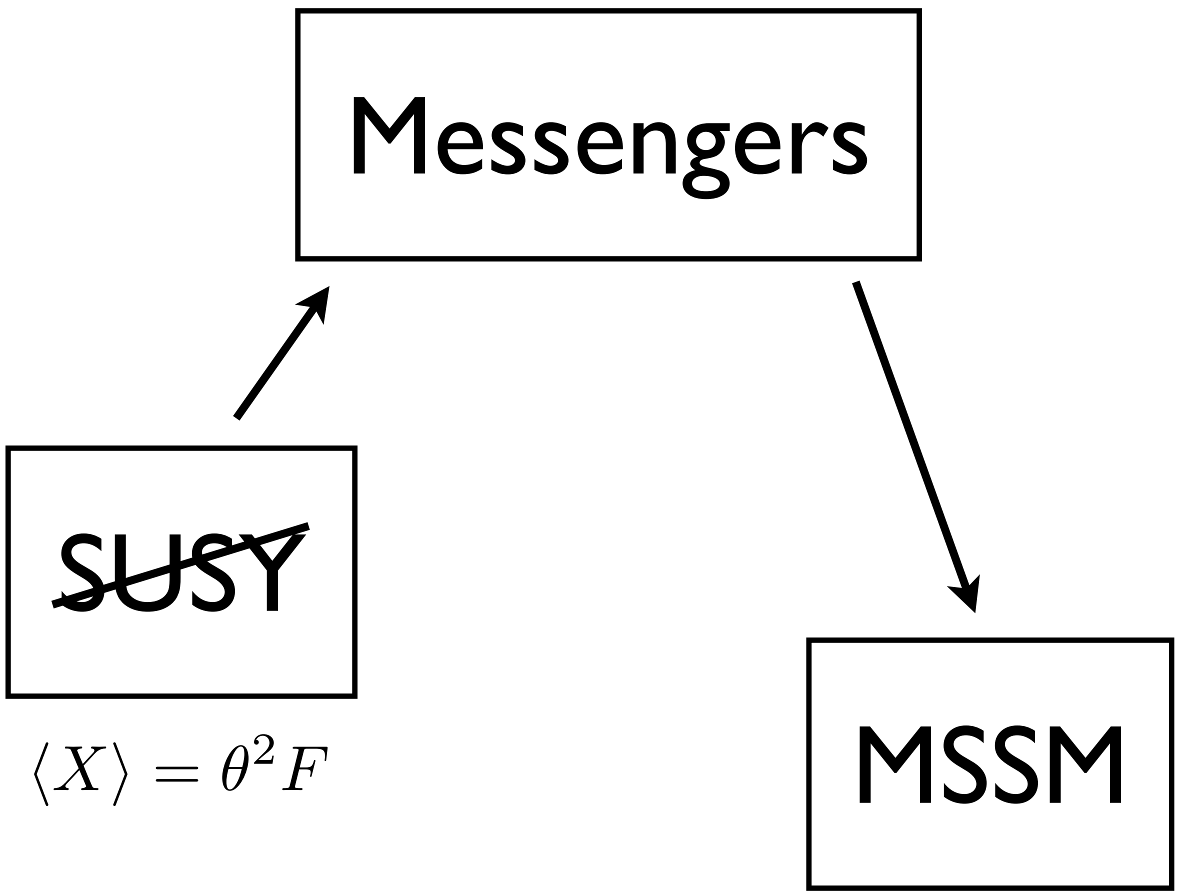
- Before the Higgs was discovered at 125 GeV, we were not forced to confront the A/m^2 problem.
- Now it is on the same footing as the μ/Bμ problem!
- Suggests there should be a common solution?

Classifying the models



$$\langle X \rangle = \theta^2 F$$

Messenger \ ~~SUSY~~	Weak	Strong
Weak	Fully calculable. Must be MGM	Incalculable? No loop factor, no problem?
Strong	Partially calculable. Hidden-sector sequestering?	

It is useful to classify the models for large A-terms based on whether the messengers and SUSY-breaking sectors are weakly or strongly coupled.

Weakly-coupled Models

A/m^2 problem => MGM

- Most general renormalizable superpotential with weakly-coupled messengers + spurion SUSY-breaking:

$$W = \kappa_{ij} X \Phi_i \Phi_j + m_{ij} \Phi_i \Phi_j$$

- Disastrous one-loop m^2 is avoided only if X is the sole source of mass in the messenger sector. (Craig, Knapen, DS, Zhao)

$$m_{ij} = 0 \ , \ \ \langle X \rangle = M + \theta^2 F \quad \Rightarrow \quad Z_Q^{(1-loop)} = c \ \log X^\dagger X$$

$$\Rightarrow \quad (m_Q^2)^{(1-loop)} = \partial_X \partial_{X^\dagger} Z_Q^{(1-loop)} = 0$$

- The messengers must be those of Minimal Gauge Mediation!
(Dine, Nelson, Shadmi, Shirman)

We recently classified all MSSM-messenger couplings consistent with perturbative SU(5) unification (Evans & DS). There are 31 couplings in all.

Turning on one coupling at a time, we surveyed the phenomenology of the resulting models.

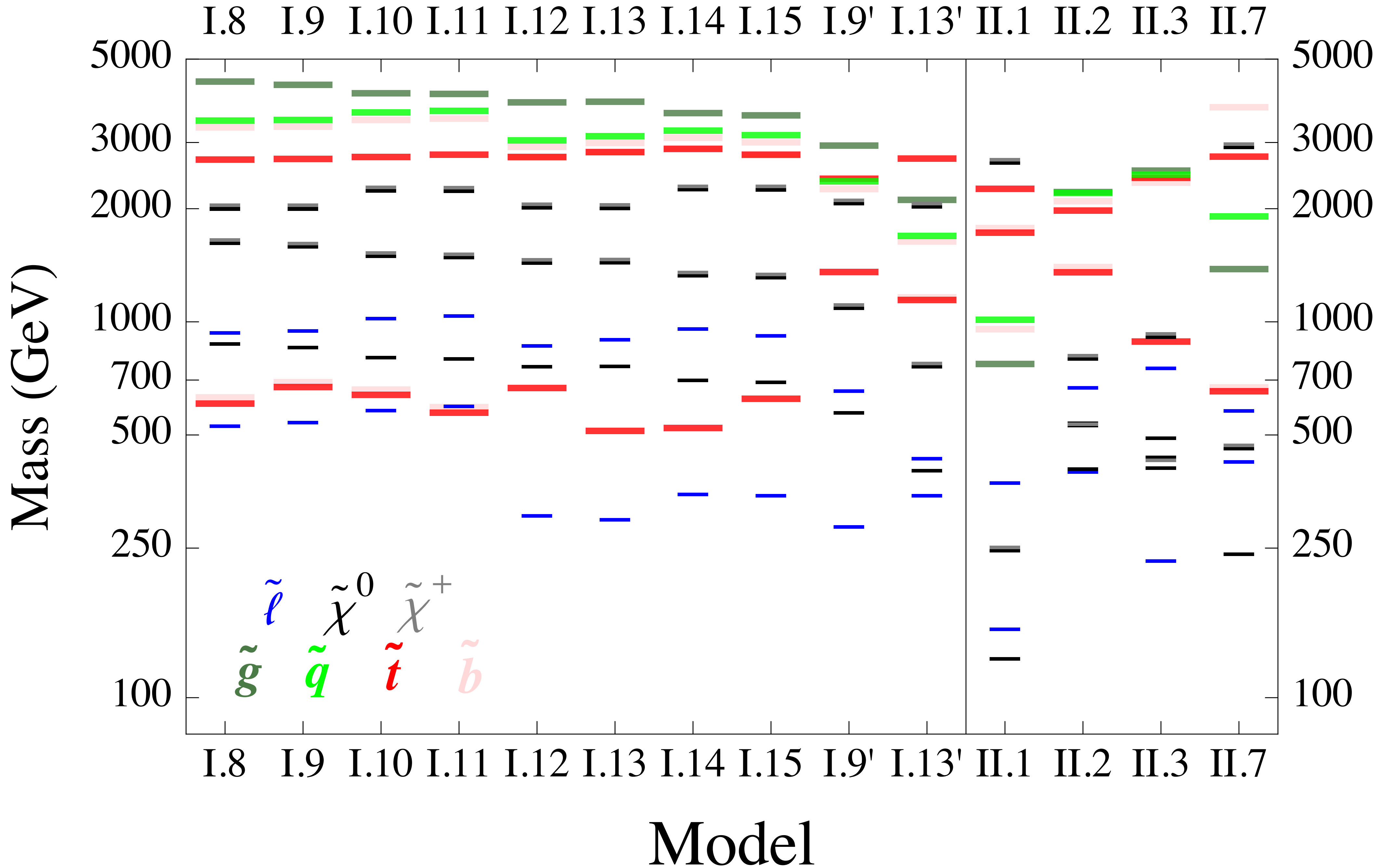
MSSM-messenger-messenger "Type I"

MSSM-MSSM-messenger "Type II"

#	Coupling	$\|\Delta b\|$	Best Point $\{\frac{\Lambda}{M}, \lambda\}$	$\|A_t\|/M_S$	$M_{\tilde{g}}$	M_S	$\|\mu\|$	Tuning
I.1	$H_u\phi_{\overline{5},L}\phi_{1,S}$	N_m	$\{0.375, 1.075\}$	1.98	3222	1842	777	3400
I.2	$H_u\phi_{10,Q}\phi_{10,U}$	$3N_m$	$\{0.25, 1.075\}$	1.99	3178	1828	789	2450
I.3	$H_u\phi_{5,\overline{D}}\phi_{\overline{10},\overline{Q}}$	4	$\{0.25, 1.3\}$	2.05	2899	1709	668	3200
I.4	$H_u\phi_{5,\overline{L}}\phi_{\overline{10},\overline{E}}$	4	$\{0.125, 0.95\}$	0.58	11134	8993	2264	4050
I.5	$H_u\phi_{\overline{5},L}\phi_{24,S}$	6	$\{0.225, 1.000\}$	0.54	13290	9785	3408	3850
I.6	$H_u\phi_{\overline{5},L}\phi_{24,W}$	6	$\{0.15, 1.025\}$	0.67	11835	8637	3259	3410
I.7	$H_u\phi_{\overline{5},D}\phi_{24,X}$	6	$\{0.3, 1.425\}$	2.04	3020	1743	576	3500
I.8	$Q\phi_{\overline{10},\overline{Q}}\phi_{1,S}$	$3N_m$	$\{0.534, 1.5\}$	2.82	4336	1274	2056	1015
I.9	$Q\phi_{\overline{5},D}\phi_{\overline{5},L}$	N_m	$\{0.353, 0.858\}$	2.67	4247	1342	2058	1015
I.10	$Q\phi_{10,U}\phi_{5,H_u}$	4	$\{0.51, 1.788\}$	2.65	4040	1318	2301	1275
I.11	$Q\phi_{10,Q}\phi_{5,\overline{D}}$	4	$\{0.378, 1.245\}$	2.76	4020	1257	2292	1260
I.12	$U\phi_{\overline{10},\overline{U}}\phi_{1,S}$	$3N_m$	$\{0.476, 1.622\}$	2.62	3815	1347	2070	1030
I.13	$U\phi_{\overline{5},D}\phi_{\overline{5},D}$	$2N_m$	$\{0.301, 0.908\}$	2.91	3829	1199	2061	1020
I.14	$U\phi_{10,Q}\phi_{5,H_u}$	4	$\{0.37, 1.352\}$	2.81	3575	1220	2312	1285
I.15	$U\phi_{10,E}\phi_{5,\overline{D}}$	4	$\{0.51, 1.972\}$	2.63	3526	1312	2310	1280
II.1	$QU\phi_{5,H_u}$	1	$\{0.55, 1.64\}$	2.02	769	1965	2738	1800
II.2	$UH_u\phi_{10,Q}$	3	$\{0.009, 1.067\}$	2.14	2203	1628	543	850
II.3	$QH_u\phi_{10,U}$	3	$\{0.269, 1.05\}$	2.27	2514	1458	439	1500
II.4	$QD\phi_{\overline{5},H_d}$	1	$\{0.37, 1.2\}$	1.78	2597	1829	3553	3020
II.5	$QH_d\phi_{\overline{5},D}$	1	$\{0.15, 1.19\}$	1.45	2497	2108	3773	6050
II.6	$QQ\phi_{5,\overline{D}}$	1	$\{0.45, 0.1\}$	0.22	7943	9870	3610	5000
II.7	$UD\phi_{\overline{5},D}$	1	$\{0.21, 1.26\}$	2.34	1374	1334	2998	2150
II.8	$QL\phi_{\overline{5},D}$	1	$\{0.14, 1.2\}$	1.51	1501	1204	2203	3700
II.9	$UE\phi_{5,\overline{D}}$	1	$\{0.445, 1.46\}$	1.89	2004	1750	3373	2730
II.10	$H_uD\phi_{24,X}$	5	$\{0.42, 1.45\}$	2.13	2943	1649	282	3500
II.11	$H_uL\phi_{1,S}$	1^*	$\{0.15, 0.675\}$	0.54	7103	8166	3714	4930
II.12	$H_uL\phi_{24,S}$	5	$\{0.296, 0.96\}$	0.53	12629	9660	3333	3780
II.13	$H_uL\phi_{24,W}$	5	$\{0.212, 0.96\}$	0.65	11487	8710	3687	3380
II.14	$H_uH_d\phi_{1,S}$	1^*	$\{0.125, 0.675\}$	0.55	7049	8051	3255	5000
II.15	$H_uH_d\phi_{24,S}$	5	$\{0.20, 1.00\}$	0.57	12047	9213	1628	4220
II.16	$H_uH_d\phi_{24,W}$	5	$\{0.2, 0.946\}$	0.64	11571	8789	3665	3460

The models with the best tuning are the type I squark models and the top-Yukawa-like type II models

Work in progress: investigating the constraints from flavor violation on these models.... (Evans, Thalapallil & DS)



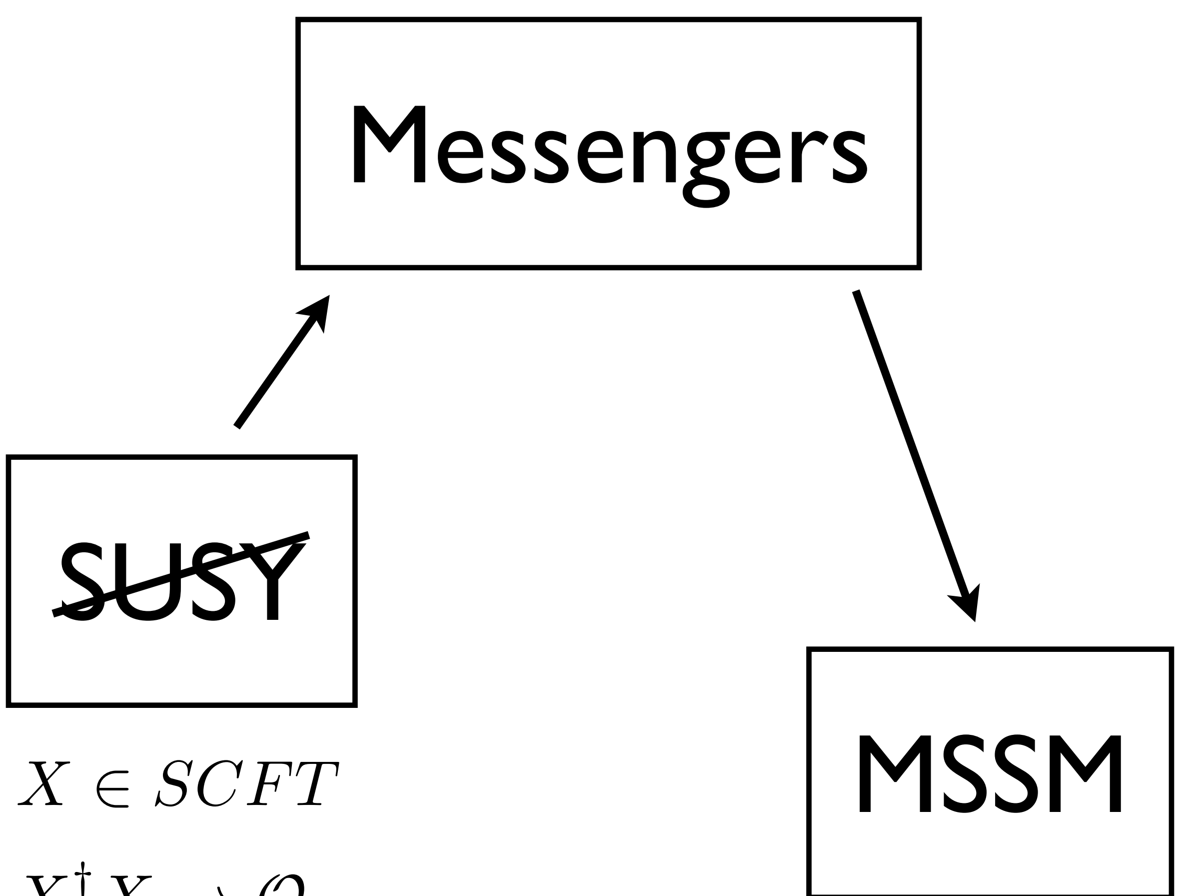
All but one of the best-tuned points with mh=125 GeV were out of reach at 7+8 TeV LHC, but could be accessible at 14 TeV LHC.
(taus+MET, multileptons, stop searches)

Is the fact that we haven't seen superpartners yet an inevitable consequence of mh=125 GeV?

Strongly-coupled Hidden Sectors

Hidden-sector sequestering

$$c_\mu \int d^4\theta \, \frac{X^\dagger}{M^{\Delta_X}} H_u H_d \quad \text{vs.} \quad c_{B_\mu} \int d^4\theta \, \frac{\mathcal{O}_\Delta}{M^\Delta} H_u H_d$$



$$X \in SCFT$$

$$X^\dagger X \to \mathcal{O}_\Delta$$

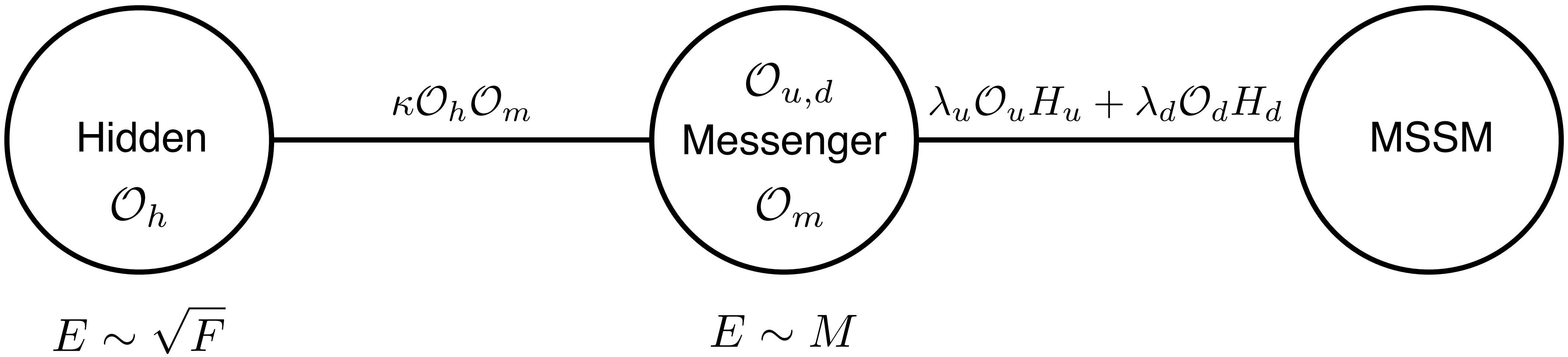
$$\gamma \equiv \Delta - 2\Delta_X > 0$$

$$B\mu \sim \left(\frac{\sqrt{F}}{M}\right)^{\Delta} \ll \mu^2 \sim \left(\frac{\sqrt{F}}{M}\right)^{2\Delta_X}$$

- Suppose X is not a spurion, but is part of a strongly interacting SCFT
- Anomalous dimensions could be used to "sequester" Bμ and solve the μ/Bμ problem. (Dine et al '04; Murayama, Nomura & Poland '07; Roy & Schmaltz '07)
- Our proposal: the same mechanism could simultaneously solve the A/m^2 problem! (Craig, Knapen & DS)

General Messenger Higgs Mediation

(Craig, Knapen & DS)



- We recently took a fresh look hidden-sector sequestering using the correlator formalism of General Gauge Mediation.
  - We derived general formulas for soft parameters valid for any hidden and messenger sector. Sequestering follows as a special case.
- Previous approaches to sequestering were cast in terms of the RG. This is more like a fixed order calculation.
- It allows for more control over the final answer!

General Higgs Mediation

- The correlator formalism of GGM was first applied to Higgs-messenger interactions by Komargodski & Seiberg '08.
- They derived formulas for μ, $B\mu$, A and $m_{H_{u,d}}^2$ to leading order ("one-loop") in $\lambda_{u,d}$, assuming a unified hidden+messenger sector.
- To study sequestering, we extended the KS results in two ways:
  - Expanded to NLO ("two-loops") in $\lambda_{u,d}$ for $B\mu$ and $m_{H_{u,d}}^2$ so that we can compare against LO μ^2 and $A_{u,d}^2$
  - Separated messenger and hidden sectors so we can take $F \ll M^2$ (cf Dumitrescu, Komargodski, Seiberg & DS '10).

Final GMHM Formulas

- Dimension 1 parameters:

$$\mu = \lambda_u \lambda_d \bar{\kappa} \, \langle \bar{Q}^2 \mathcal{O}_h^\dagger \rangle_h \int d^4y \, \left\langle \mathcal{O}_m^\dagger(y) \ldots \right\rangle_m$$

$$A_{u,d} = |\lambda_{u,d}|^2 \bar{\kappa} \, \langle \bar{Q}^2 \mathcal{O}_h^\dagger \rangle_h \int d^4y \, \left\langle \mathcal{O}_m^\dagger(y) \ldots \right\rangle_m$$

$$\propto \sqrt{F}^{\Delta_h + 1}$$

- Dimension 2 parameters:

$$B\mu = \lambda_u \lambda_d |\kappa|^2 \int d^4y d^4y' \left\langle Q^4 \left(\mathcal{O}_h^\dagger(y) \mathcal{O}_h(y') \right) \right\rangle_{h,full} \left\langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \right\rangle_{m,full}$$

$$m_{H_{u,d}}^2 = |\lambda_u|^2 |\kappa|^2 \int d^4y d^4y' \left\langle Q^4 \left(\mathcal{O}_h^\dagger(y) \mathcal{O}_h(y') \right) \right\rangle_{h,full} \left\langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \right\rangle_{m,full}$$

$$\propto ??$$

$B\mu$ and $m_{H_{u,d}}^2$ depend on the same hidden-sector 2-pt function

Answers organize themselves into full correlators (connected + disconnected)

OPE and sequestering

$$B\mu = \lambda_u \lambda_d |\kappa|^2 \int d^4y d^4y' \left\langle Q^4 \left(\mathcal{O}_h^\dagger(y) \mathcal{O}_h(y') \right) \right\rangle_{h,full} \left\langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \right\rangle_{m,full}$$

- Because of the messenger correlator, the integral is dominated by

$$|y - y'| < 1/M \ll 1/\sqrt{F}$$

- If the hidden sector is close to a fixed point at the scale M, we can use the OPE to simplify the 2-pt function!

$$\mathcal{O}_h(y) \mathcal{O}_h^\dagger(y') \sim |y - y'|^{-2\Delta_h} \mathbf{1} + \mathcal{C}_\Delta |y - y'|^\gamma \mathcal{O}_\Delta(y') + \ldots$$

- Then Bμ (and $m_{H_{u,d}}^2$) becomes:

$$B\mu = \lambda_u \lambda_d |\kappa|^2 \langle Q^4 \mathcal{O}_\Delta \rangle_h \int d^4y d^4y' \, |y - y'|^\gamma \left\langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \right\rangle_{m,full}$$

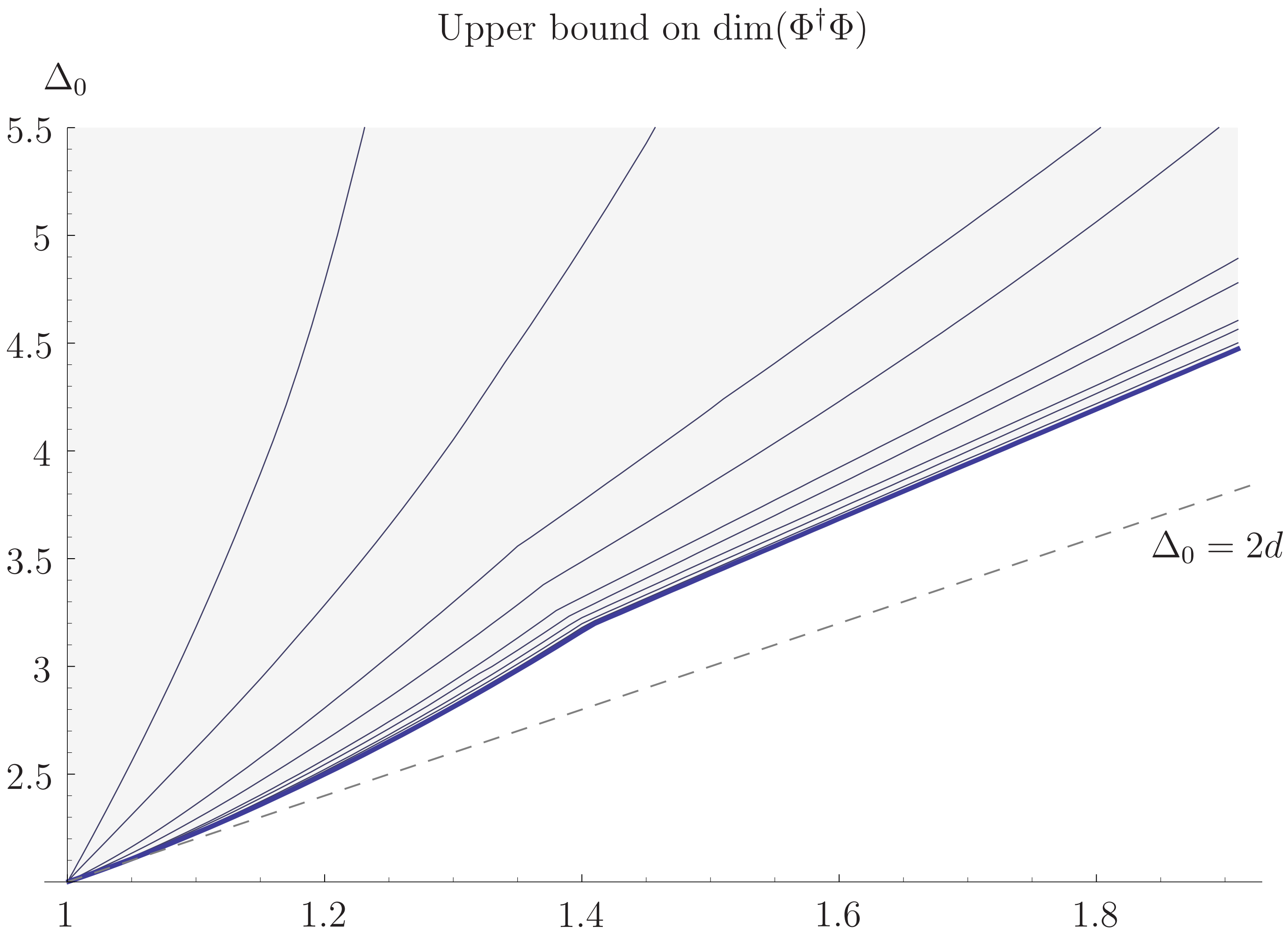
$$\propto \sqrt{F}^{\Delta+2}$$

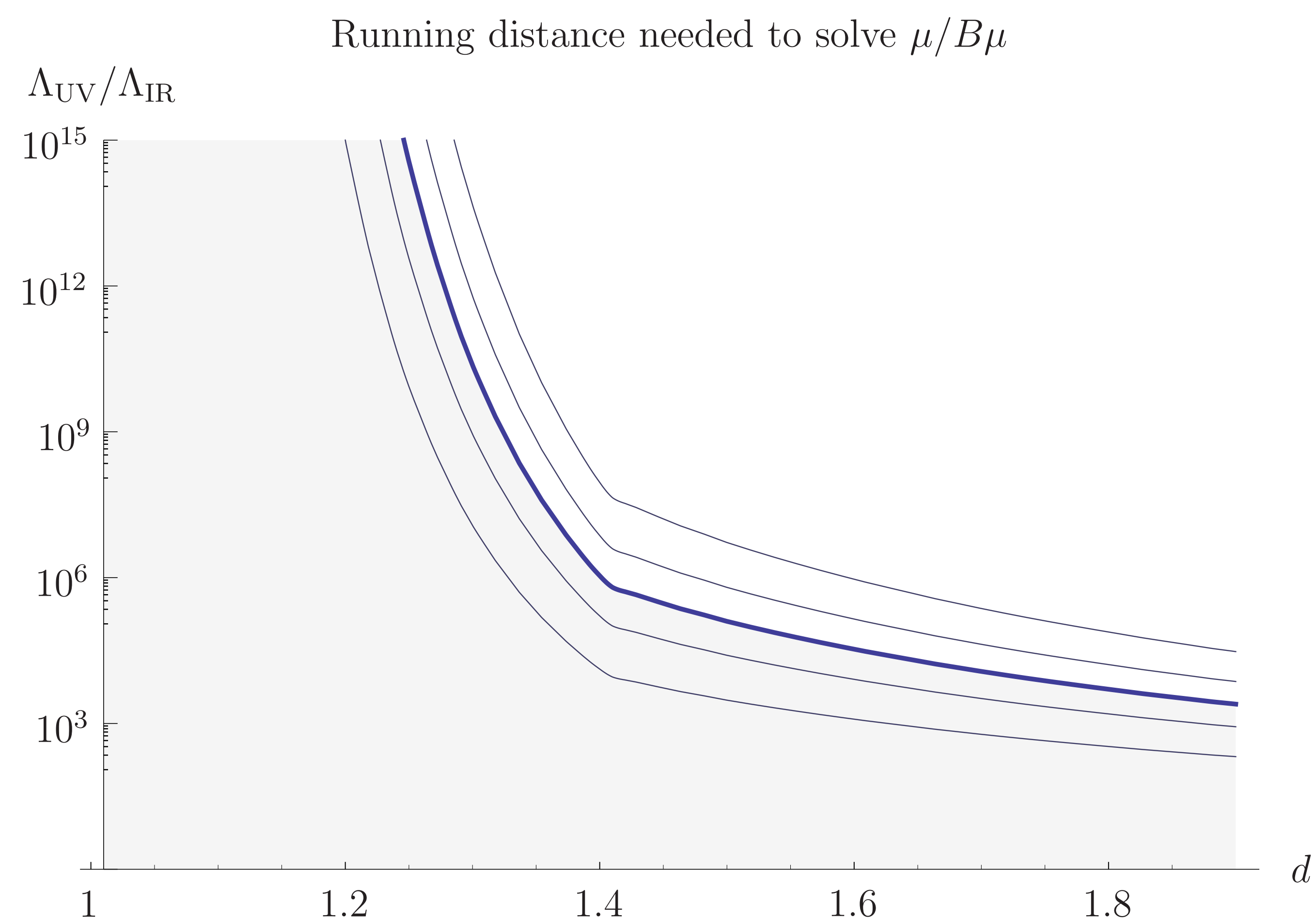
Sequestering!

Applications of our result

$$B\mu = \lambda_u \lambda_d |\kappa|^2 \langle Q^4 \mathcal{O}_\Delta \rangle_h \int d^4y d^4y' \, |y-y'|^\gamma \left\langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \right\rangle_{m,full}$$

- We are currently working on applying our result to study models where the sequestering is not total.
  - Total sequestering would be $B\mu = 0, \;\; m^2_{H_{u,d}} = -|\mu|^2$ .This boundary condition actually has a lot of trouble achieving EWSB (Perez, Roy, Schmaltz; Asano, Hisano, Okada, Sugiyama)
  - Total sequestering requires long enough running with large enough anomalous dimension γ. However there are strong bounds on γ from the conformal bootstrap that limit this possibility. (Poland, Simmons-Duffins, Vichi)





Poland, Simmons-Duffins, Vichi

Applications of our result

$$B\mu = \lambda_u \lambda_d |\kappa|^2 \, \langle Q^4 \mathcal{O}_\Delta \rangle_h \int d^4y d^4y' \, |y-y'|^\gamma \, \langle \mathcal{O}_m^\dagger(y) \mathcal{O}_m(y') \ldots \rangle_{m,full}$$

- We are currently working on applying our result to study models where the sequestering is not total. (Knapen & DS)
  - Total sequestering would be $B\mu = 0, \;\; m^2_{H_{u,d}} = -|\mu|^2$ .This boundary condition actually has a lot of trouble with achieving EWSB (Perez, Roy, Schmaltz; Asano, Hisano, Okada, Sugiyama)
  - Total sequestering requires long enough running with large enough anomalous dimension γ. However there are strong bounds on γ from the conformal bootstrap that limit this possibility. (Poland, Simmons-Duffins, Vichi)
- This motivates us to study "partially sequestered" models where Bμ and $m_{Hu,d}^2+|\mu|^2$ are not completely set to zero.
- For this the GMHM formulas are absolutely essential!

Summary

- In this talk, we have surveyed the different ways to achieve mh=125 GeV in supersymmetric models.
  - Very heavy stops ("mini-split SUSY")
  - Large A-terms ("maximal mixing")
  - Non-decoupling F-terms (e.g NMSSM)
  - Non-decoupling D-terms
- No option is particularly compelling. Each has pros and cons. The tuning ranges from ~10% in the best cases to ~10^{-8} in the worst.
- Maybe we're not "measuring" tuning correctly...

Summary

- Focusing on minimal SUSY, we also surveyed the different ways to generate large A-terms from UV models
  - A-terms from RG
    - need heavy gluinos and high messenger scale
  - A-terms from MSSM/messenger interactions
    - the A/m^2 problem
    - weakly coupled: messengers must be MGM-type
    - strongly coupled: hidden sector sequestering is a viable option.
    - New framework of GMHM provides a powerful unified framework for describing all models of direct messenger-Higgs couplings.

The End