Phenomenology of a simple quiver

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Works in progress in collaboration with
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Outline

- SUSY models and a Higgs at ~126 GeV

- Some theoretical developments

- A SMxEW quiver model...

- ...and its phenomenology

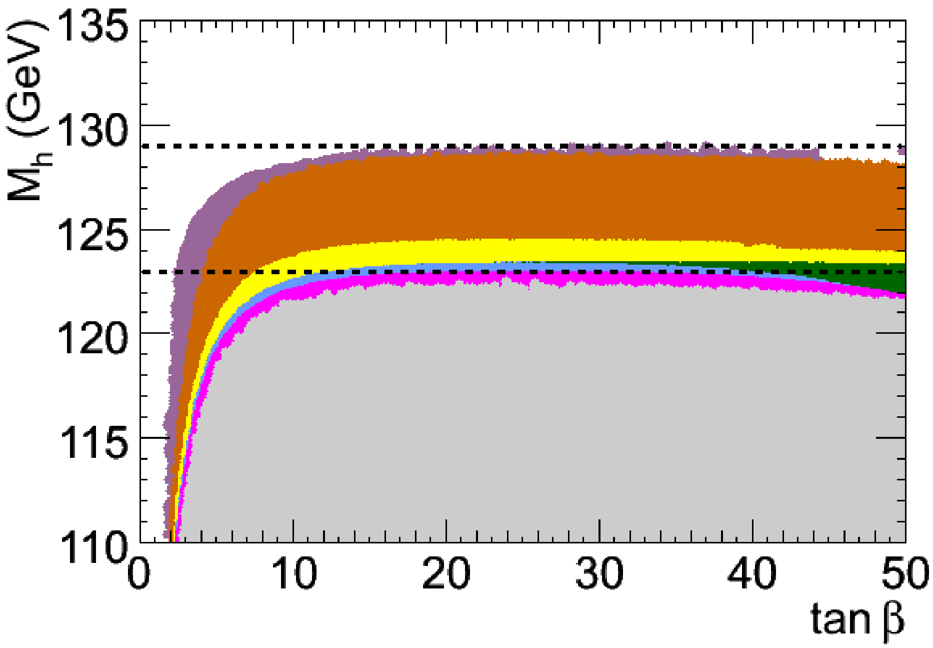
- Summary and perspectives

SUSY models and a Higgs at 126 GeV

- The LHC has observed a new particle with a mass of ~126 GeV which can, for the moment, be described by a Higgs boson (i.e. a scalar that could at least partly trigger EWSB).

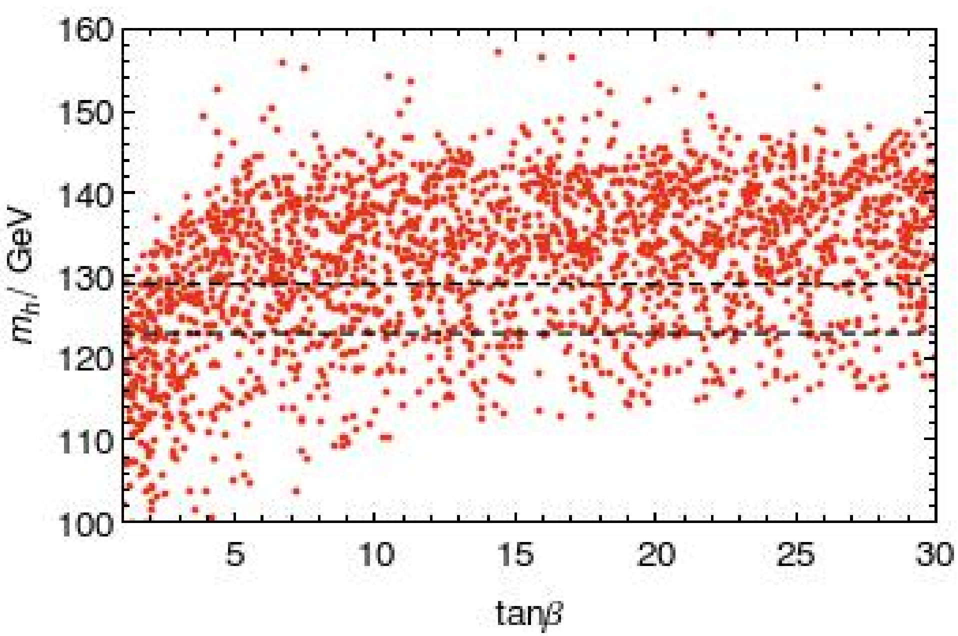
- No signs of superpartners yet.

Current status of MSSMs



Arbey, Battaglia, Djouadi, Mahmoudi, arXiv:1207.1348

Minimal quiver model



A. Bharucha, A.G., M. McGarrie, to appear

Theoretical developments

- In recent years, a new framework was introduced to study GMSB : GGM.

→ **In the limit where the gauge couplings vanish, the MSSM is decoupled from the ~~SUSY~~ sector.**

This made it possible to define somewhat the equivalent of mSUGRA for GMSB, based on a handful of parameters

$$\Lambda_G,\ \Lambda_S,\ M_{mess},\ N,\ \text{sign}(\mu),\ \tan(\beta)$$

(depending on taste)

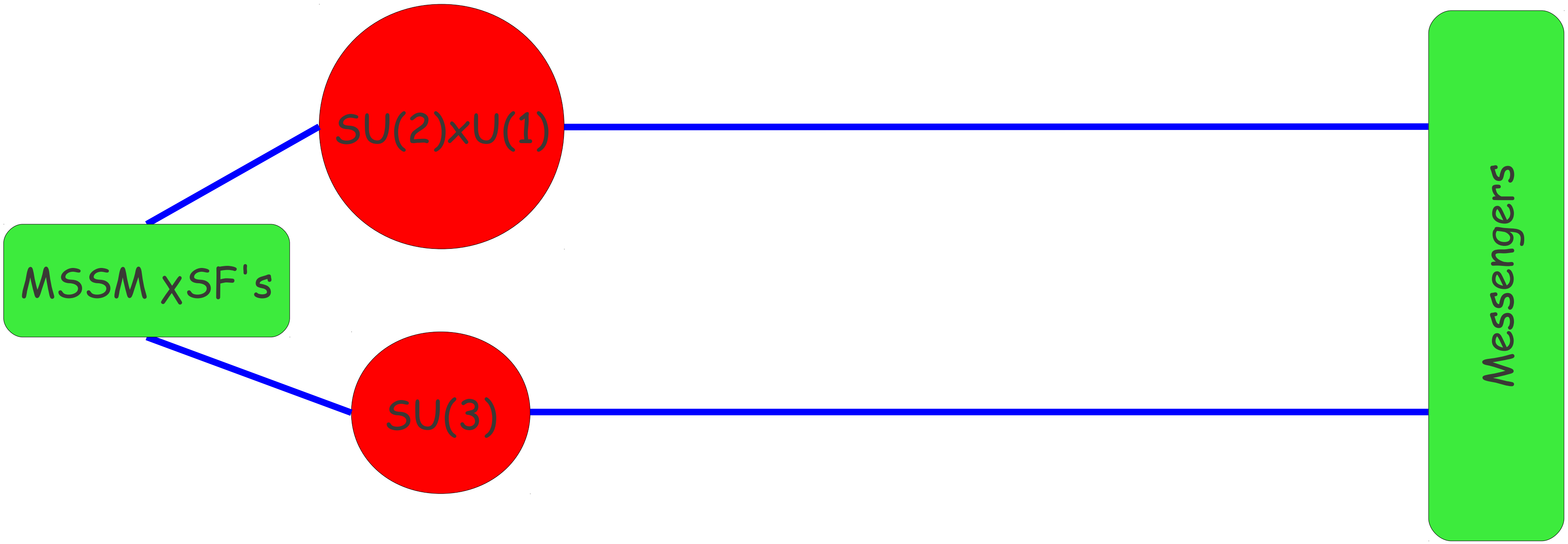
- Moreover, for quite some time, people have considered ~~SUSY~~ from extra dimensions.

- And the two can be combined! *(cf Moritz McGarrie's talk on Thursday!)*

- In many X-D/strongly coupled/metastable SUSY-breaking scenarios, a quiver-like structure appears : messengers not directly charged under the MSSM.

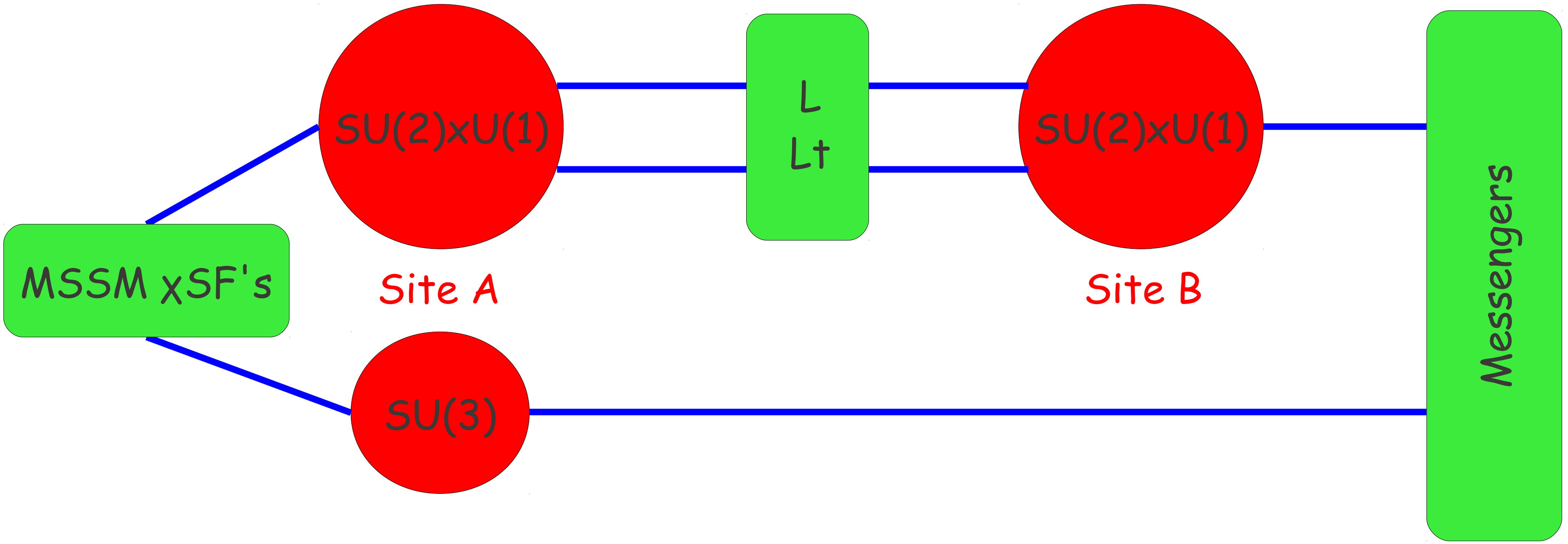
→ **Interpolation between mGMSB and X-D mediation!**

A minimal quiver



- Start form the usual mGMSB setup.

A minimal quiver



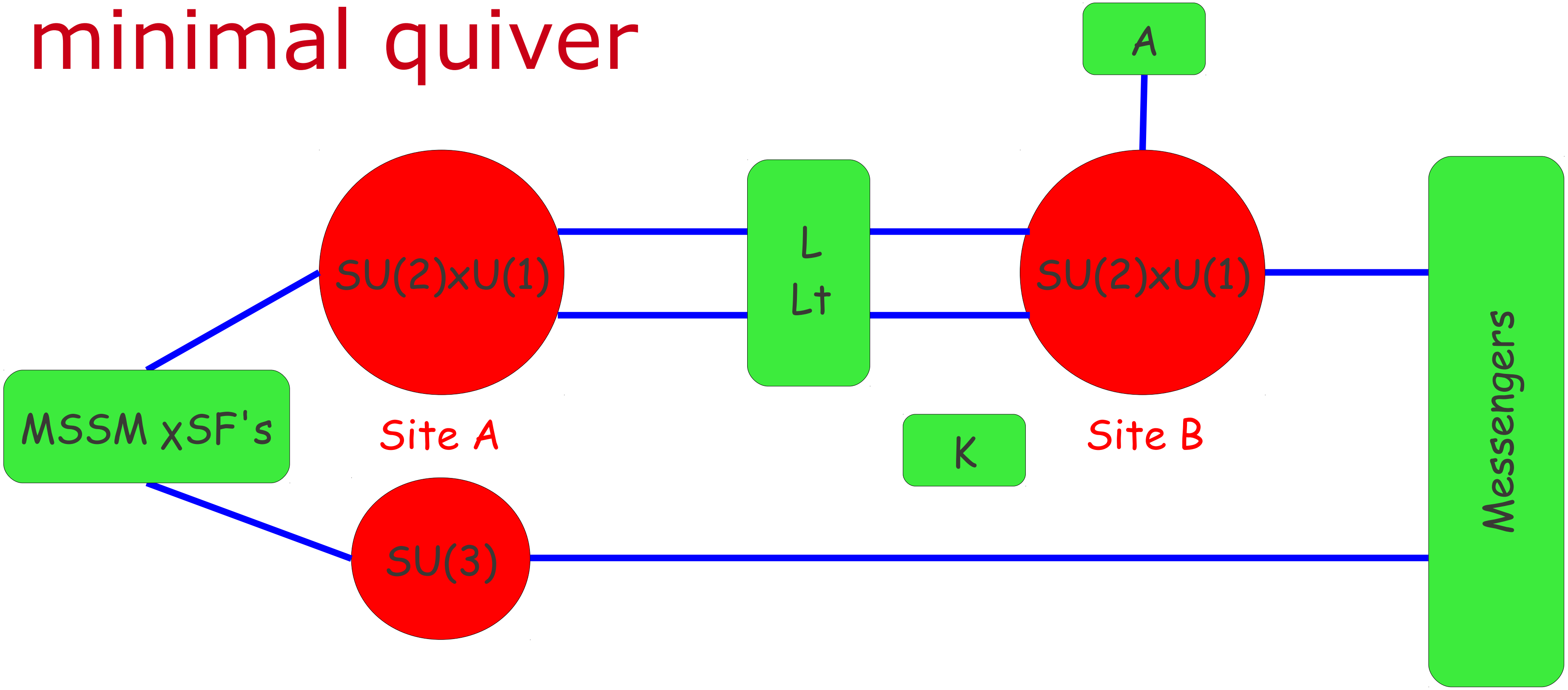
- Start form the usual mGMSB setup.

- Interject between SU(2)xU(1) and the messenger sector another SU(2)xU(1) gauge group and only charge the messengers under site B and SU(3).

- Introduce a pair of bifundamentals L, Lt to break $(SU(2)xU(1))^2$ down to the diagonal.

→ But turns out some components of L, Lt remain massless!

A minimal quiver



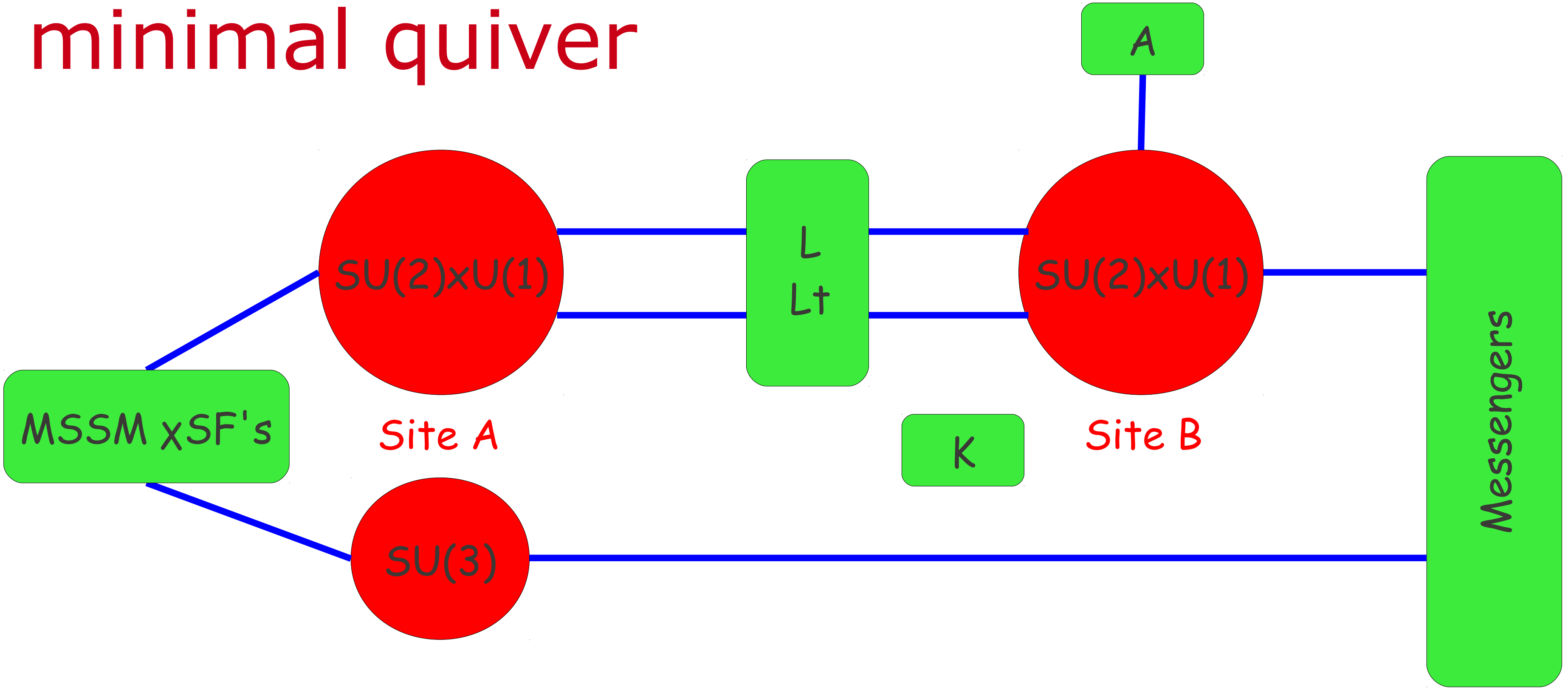
- Start form the usual mGMSB setup.

- Interject between SU(2)xU(1) and the messenger sector another SU(2)xU(1) gauge group and only charge the messengers under site B and SU(3).

- Introduce a pair of bifundamentals L, Lt to break $(SU(2)xU(1))^2$ down to the diagonal.

- Finally, introduce a B-adjoint A and a singlet K to give masses to all L, Lt components.

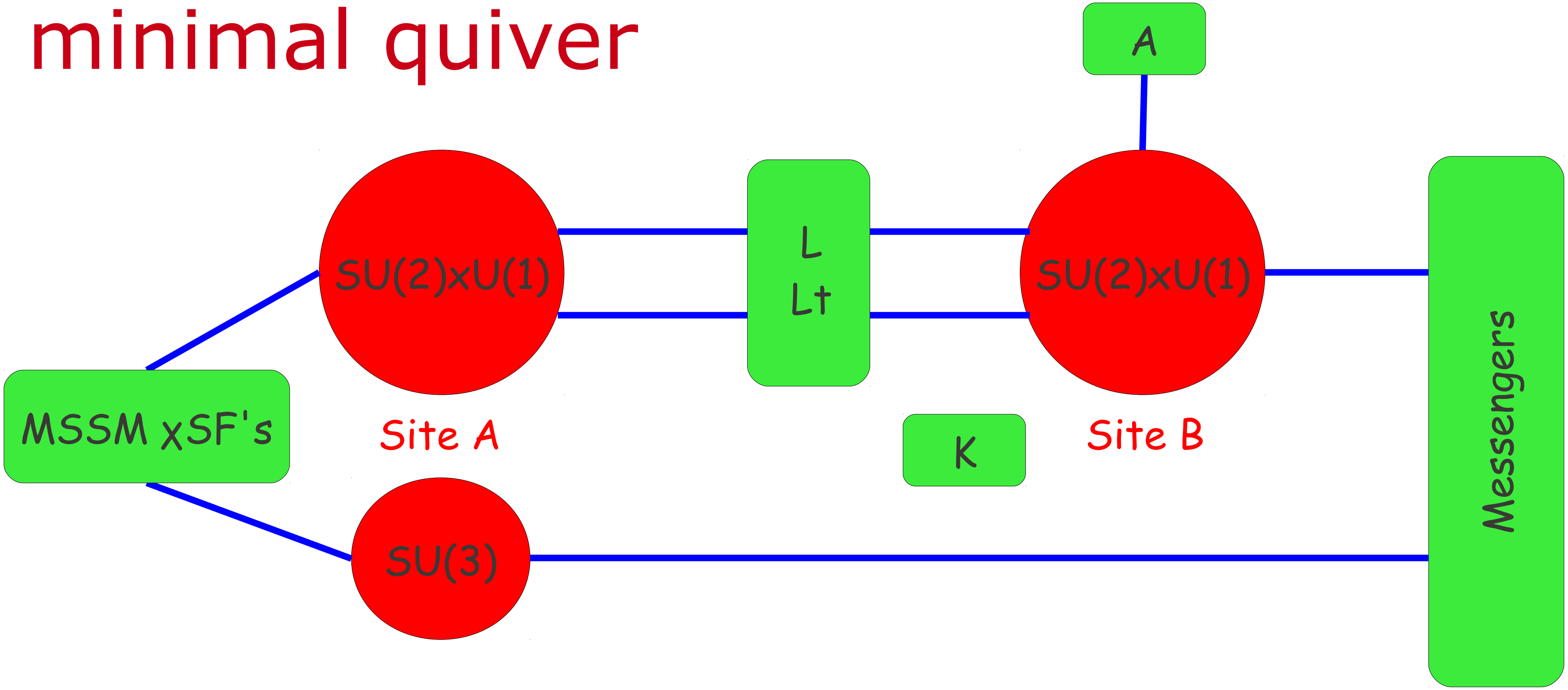
A minimal quiver



- The bifundamental-type diagonal breaking makes it so that only respective gauge bosons/gauginos mix (B_A-B_B, W_{A1}-W_{B1} etc).

- The bifundamental-type breaking ensures that MSSM SF's transform under the diagonal subgroup the same way as under the site *A* group.

A minimal quiver



The superpotential we consider reads:

$$W_{\rm SSM} = Y_u\, \hat{u}\, \hat{q}\, \hat{H}_u \; - Y_d\, \hat{d}\, \hat{q}\, \hat{H}_d \; - Y_e\, \hat{e}\, \hat{l}\, \hat{H}_d \; + \mu\, \hat{H}_u\, \hat{H}_d$$

$$W_{\rm Quiver} = \frac{Y_K}{2} \hat{K}(\, \hat{L}\, \hat{\tilde{L}} \, - V_L^2) \, + Y_A\, \hat{L}\, \hat{A}\, \hat{\tilde{L}}$$

+ we have assumed some O'Raifeartaigh-like SUSY breaking.

Some consequences

The quiver structure has a series of distinct consequences :

- At the messenger scale, GMSB soft masses are generated for the site $\mathcal{B}$ gauginos, the gluinos, and the linking field scalars.

- The MSSM gaugino soft masses are not exactly GMSB – type. They depend on the GMSB scheme ***and*** $\mathcal{A}/\mathcal{B}$ mixing.

- The MSSM **scalar soft masses** are generated at two-loops, but they are suppressed by the linking scale. This opens up a possibility for **light sfermions**!

McGarrie, arXiv:1009.0012
McGarrie, arXiv:1101.5158
Auzzi, Giveon, Gudnason arXiv:1110.1453

- **L/R stop mixing** can be substantially **larger** than in usual mGMSB.

- The MSSM **D-terms** get modified as a consequence of integrating out the heavy goldstones → new contributions that can **raise the Higgs mass**! These terms can be **non-decoupled** and can contribute significantly to m_h.

e.g. Huo, Lee, Thalapillil, Wagner arXiv:1212.0560

Implementing a quiver

The implementation of the model was done by means of the SARAH package (*cheers to the chairman for tolerating us!*) and by intervening in the generated SPheno code by hand.

Staub arXiv:1207.0906 / Staub, Ohl, Porod, Speckner arXiv:1109.5147

→ RGE running performed at 2 loops both below and above the threshold scales.

→ Finite shifts implemented carefully with the help of SARAH and by customizing the resulting Spheno code.

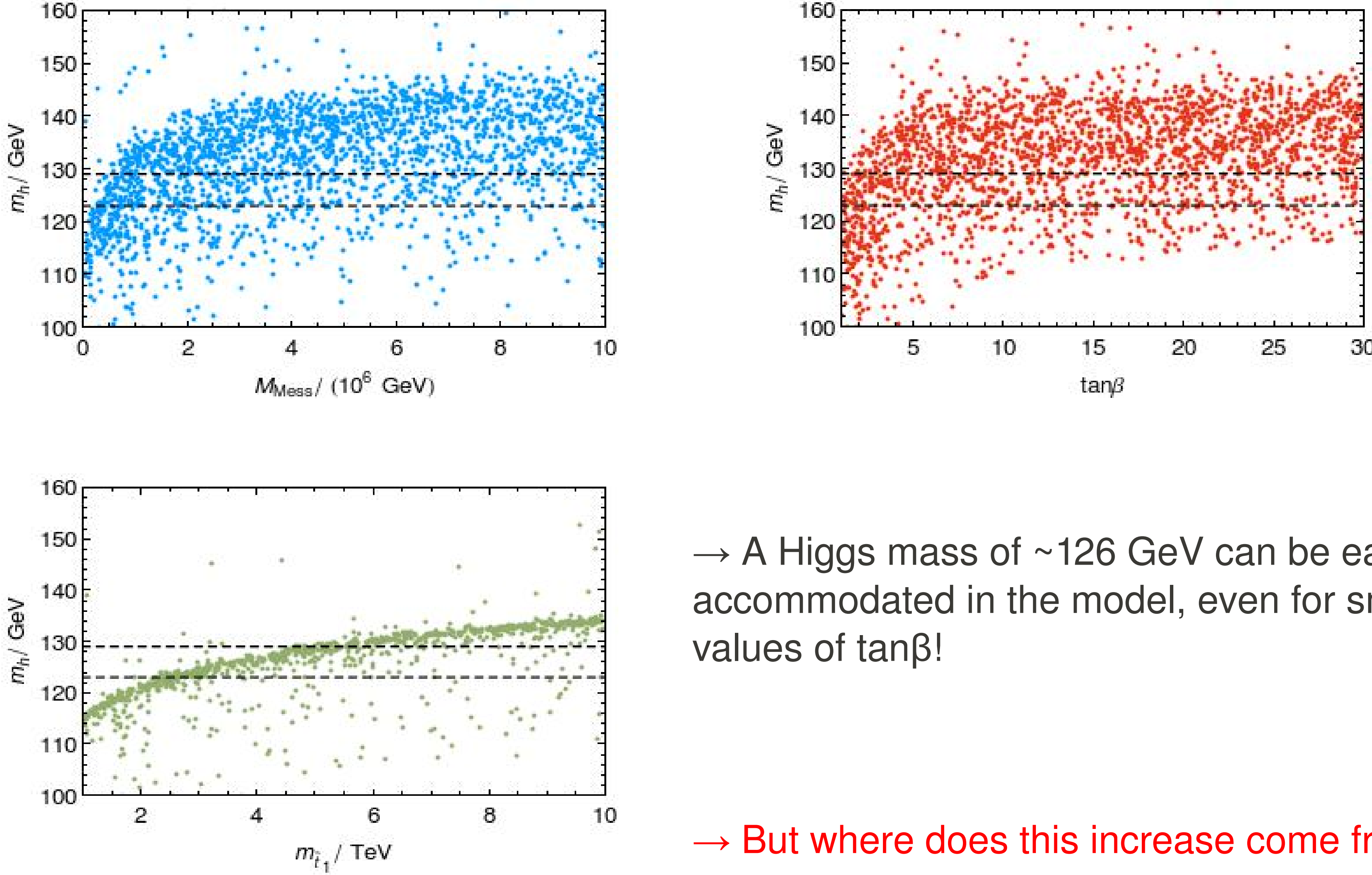
→ Full boundary conditions implemented.

→ Possibility (that we exploit!) to impose most state of the art phenomenological constraints from colliders, flavour physics and so on.

→ Extra D-terms calculated and added by hand.

→ The framework is now there and can be extended quite easily!

Results : the Higgs mass



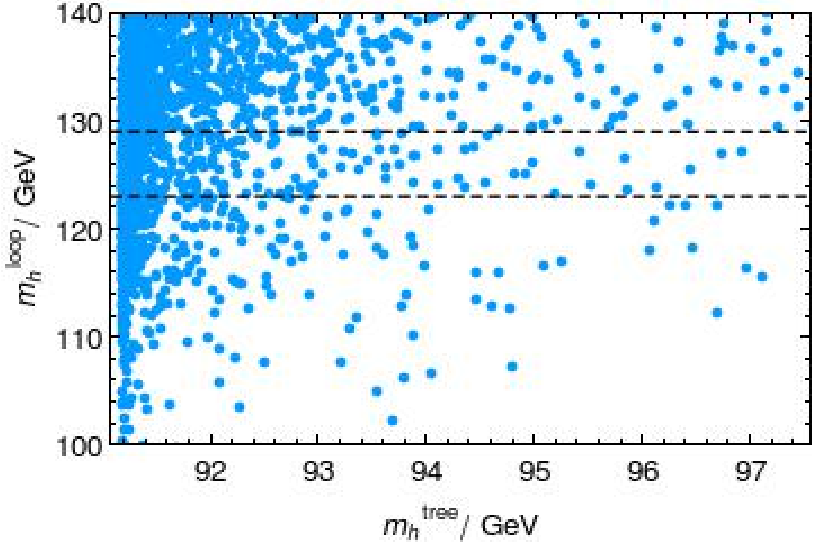
→ A Higgs mass of ~126 GeV can be easily accommodated in the model, even for small values of tanβ!

→ But where does this increase come from?

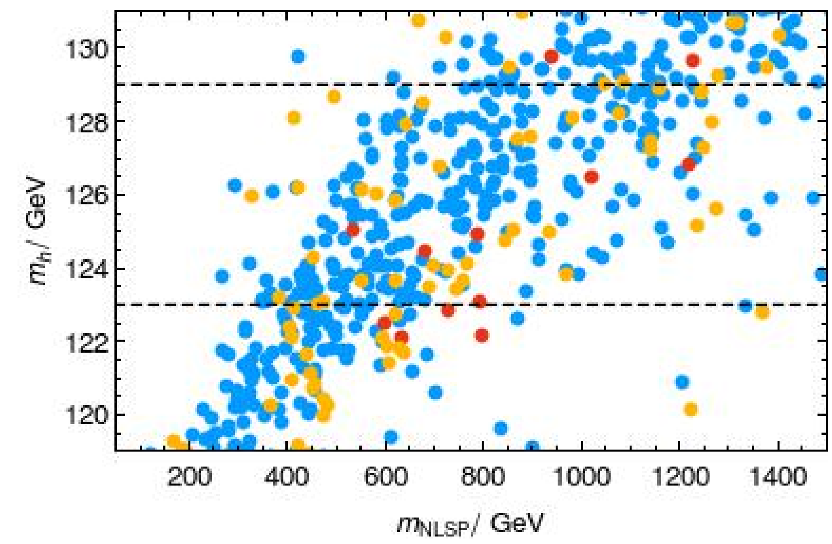
(m_t = 173.2 GeV)

Results : Anatomy of m_h and the NLSP

m_h^{tree} vs m_h^{full}

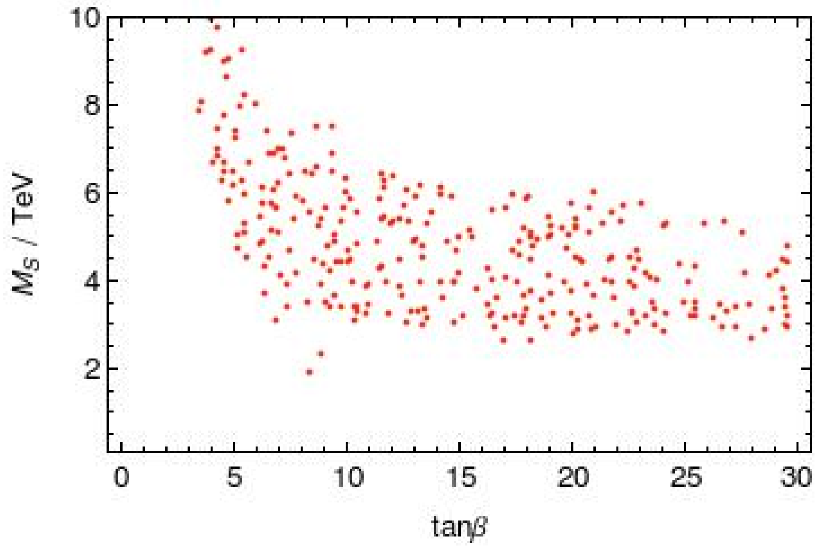


m_h vs m_{NLSP}



(stau, sneutrino, neutralino)

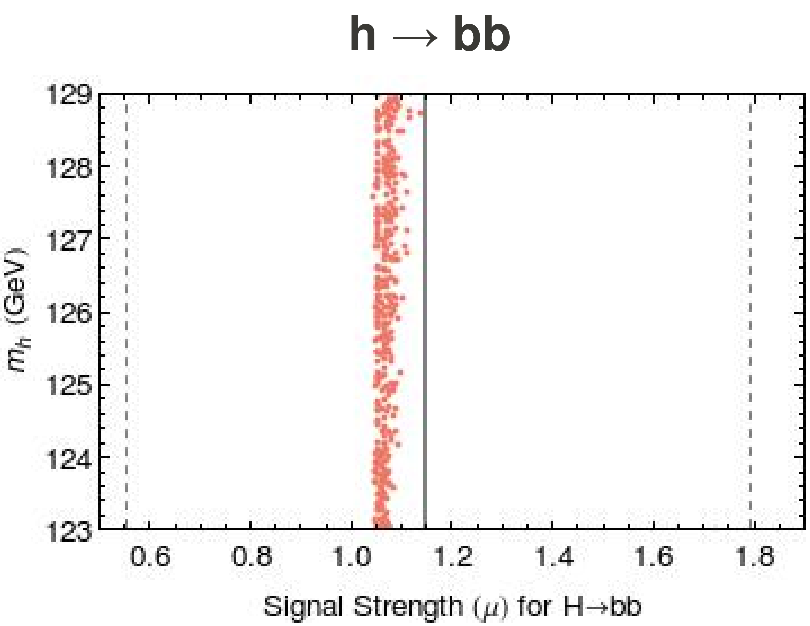
tanβ vs M_s for $123 < m_h < 129$ GeV

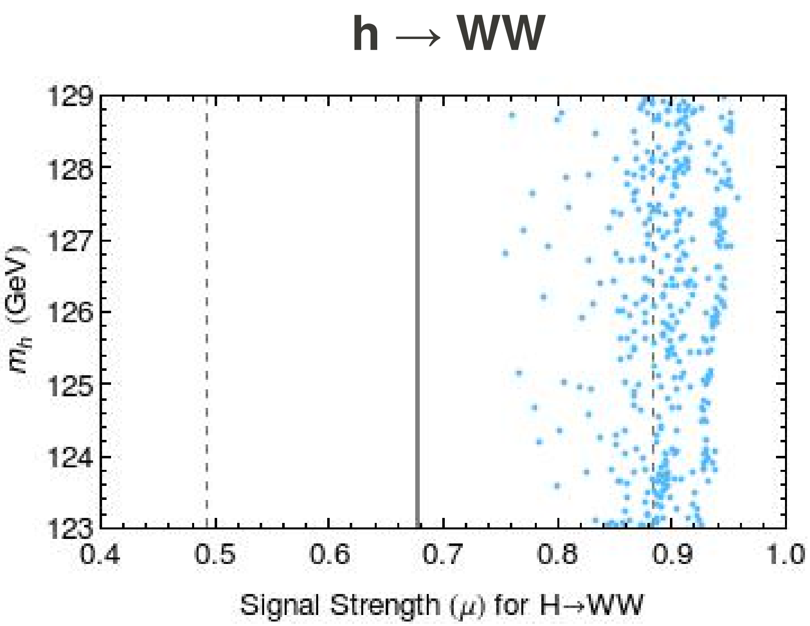


→ Despite stops lying in the TeV range, multiple non-colored sparticles can lie below 500 GeV.

→ Interesting phenomenology for LHC14?

Results : Higgs signal strengths (CMS)





Previous analyses had expressed concerns about the presence of the non-decoupled D-terms enhancing d-type higgs couplings. A few remarks are in order :

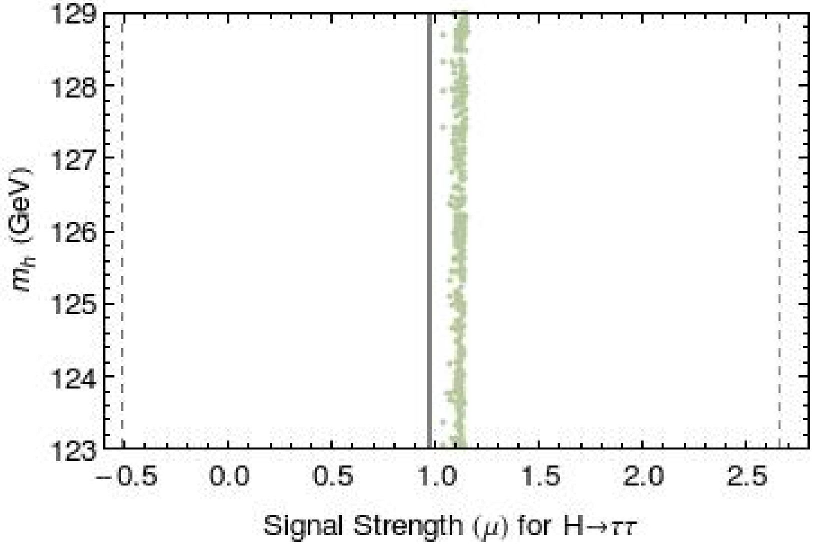
→ h → bb was (and is) very uncertain. Same for h → ττ , which didn't even exist at the time.

→ The D-term contribution was taken to be too large (note that usually these terms were studied quasi-independently of the full model!).

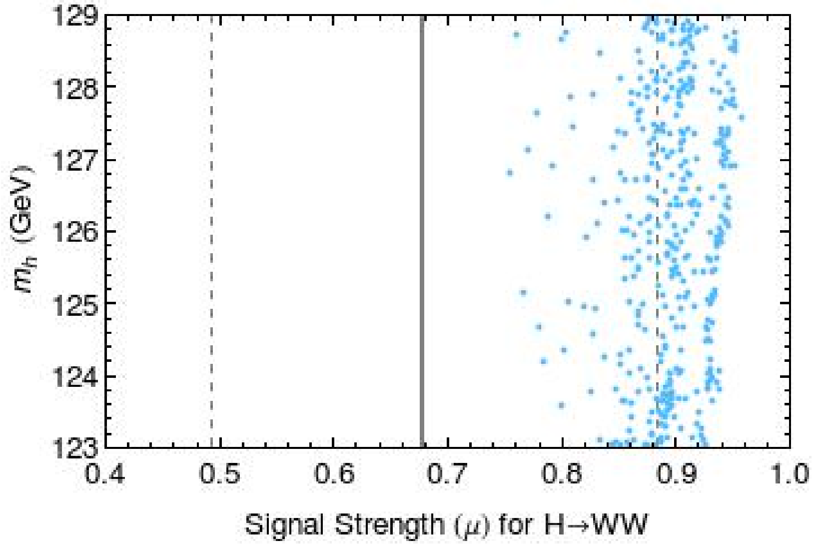
→ But h → WW might turn out to be very interesting!

Results : Higgs signal strengths (CMS)

h → ττ



h → WW



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Summary and perspectives

- From a top-down point of view, quiver gauge theories are a well-motivated class of models to communicate SUSY breaking to the visible sector.

- From a bottom-up point of view, one has a GMSB-type mechanism (DM candidate, no FCNCs......) that can easily give a ~125 GeV Higgs with correct properties.

- With the minimal $(SU(2)\times U(1))^2$ setup, it seems difficult to avoid heavy stops to get the higgs mass right. But :
→ not as heavy as in mGMSB
→ non-colored sparticles can be light by construction!

- We now possess a machinery to properly analyse quiver models.

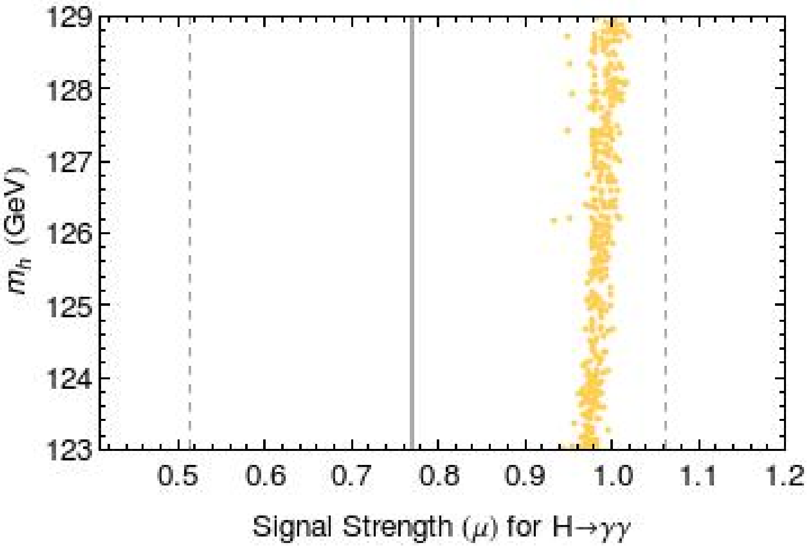
Many open questions :

- What about DM? What if we quiver $SU(3)$?
- Kinetic mixing should be there. What would be its impact?
- How low can we take the linking scale? New signatures for LHC14? → A technically challenging implementation!
- How are things modified with a strongly coupled sector?

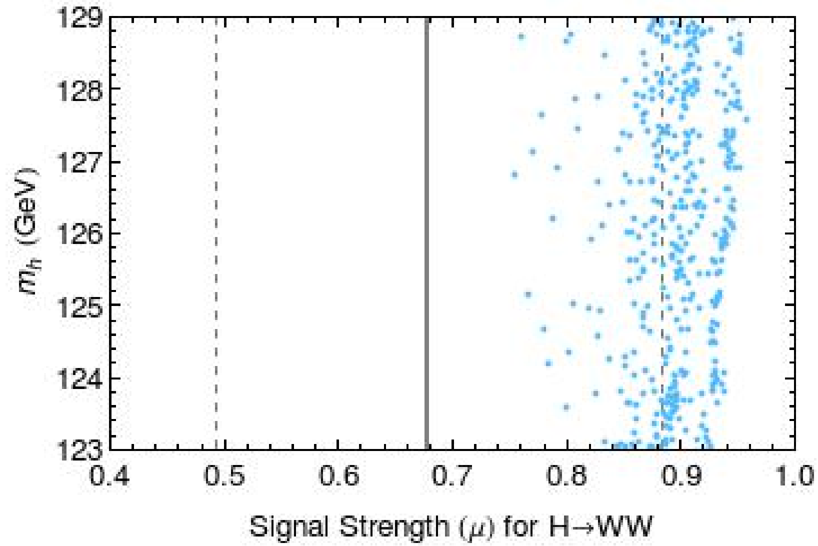
Thank you!

More Higgs signal strengths (CMS)

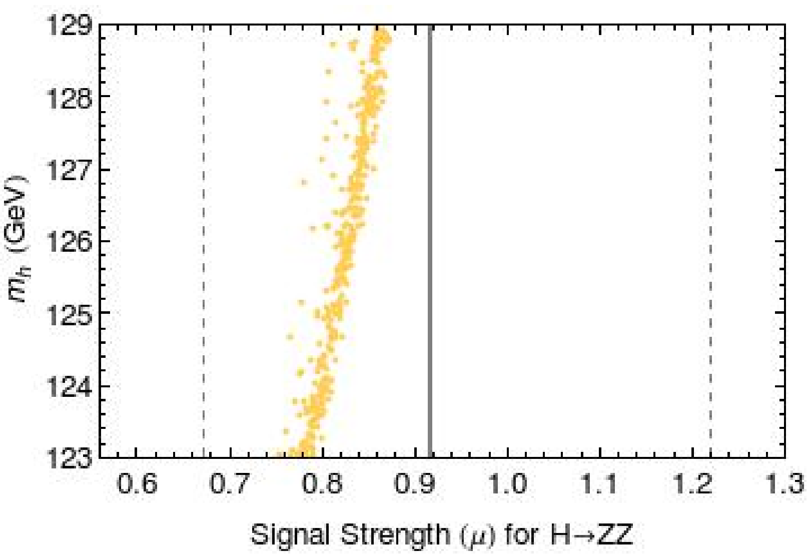
h → γγ



h → WW



h → ZZ



Interestingly, h → WW might turn out to be a crucial test for this model.

→ A possibility that has gone unnoticed!

Quiver breaking

The assignment of vev's goes as

$$\langle L \rangle = \left\langle \tilde{L} \right\rangle = v\mathbb{I}_{2\times 2}$$

with the low-energy gauge couplings and massive gauge bosons being

$$\frac{1}{g_i^2} = \frac{1}{g_{Ai}^2} + \frac{1}{g_{Bi}^2}\ ,\ g_i^2 = \frac{g_{Ai}^2 g_{Bi}^2}{g_{Ai}^2 + g_{Bi}^2} \quad , \quad g_3 = g_3$$

$$m_{v,i}^2 = 4(g_{A,i}^2 + g_{B,i}^2)v^2$$

whereas the *A*,B site mixing can be parametrized by two angles

$$\cos\theta_1 = \frac{g_1}{g_{A1}}, \quad \cos\theta_2 = \frac{g_2}{g_{A2}}, \quad \sin\theta_1 = \frac{g_1}{g_{B1}}, \quad \sin\theta_2 = \frac{g_2}{g_{B2}}$$

Non-decoupled D-terms

When heavy dof's are integrated out, we get additional pieces in the low-energy lagrangian. Among others :

$$\delta\mathcal{L} = -g_1^2\Delta_1(H_u^\dagger H_u - H_d^\dagger H_d)^2 - g_2^2\Delta_2\sum_a(H_u^\dagger\sigma^a H_u + H_d^\dagger\sigma^a H_d)^2$$

Where

$$\Delta_1 = \left(\frac{g_{A1}^2}{g_{B1}^2}\right)\frac{2m_L^2}{m_{v1}^2 + 2m_L^2} \quad , \quad \Delta_2 = \left(\frac{g_{A2}^2}{g_{B2}^2}\right)\frac{2m_L^2}{m_{v2}^2 + 2m_L^2}$$

This results in a modification of the higgs tree-level mass as :

$$m_h^2 \simeq m_z^2\cos 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v_{ew}^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12m_{\tilde{t}}^2}\right)\right]$$

$$m_z^2 \to m_z^2 + \left(\frac{g_1^2\Delta_1 + g_2^2\Delta_2}{2}\right)v_{ew}^2$$