Higgs Beyond the Standard Model: Expectations in Strongly vs Weakly Interacting Theories

Matthew Reece Harvard University at Higgs Couplings, Freiburg, October 2013 The organizers asked me 'to present a REVIEW TALK about "Strongly interacting physics versus weakly interacting SUSY and/or non-SUSY approaches"'

A big topic! There are many new physics models of both types.

I'll discuss the two general ideas I think are most plausible: composite Higgs and SUSY.

Both are becoming at least moderately tuned in light of data.

A COMPOSITE HIGGS

A generic composite Higgs would come with many other composite resonances. So we usually consider composite Higgses that are *pseudo-Nambu-Goldstone* bosons.

(Georgi, Kaplan 80s; recent review: R. Contino, 1005.4269)

$G \rightarrow H$ *f*

E.g. $SO(5) \rightarrow SO(4)$: one complex Higgs doublet.

EWSB FOR COMPOSITES

A potential is generated for the Higgs by *G*-violating couplings. Usually this is done with elementary top quarks coupled to composite top-like fermions.

$$
V(h) \sim \frac{a\lambda^2}{16\pi^2} \cos(h/f) + \frac{b\lambda^2}{16\pi^2} \sin^2(h/f)
$$

Both terms contain h^2 and h^4 pieces, so $v \ll f$ is always a *tuning:* (Exception: "little Higgs" theories with extended symmetry structure.) $-2\cos(h/f) - (1+\epsilon)\sin^2(h/f) \Rightarrow \langle h \rangle^2 \approx 2\epsilon f^2$

Expect *v/f* **corrections to be large, if EWSB is natural.**

WHERE IS THE SCALE?

Before even looking at Higgs properties, we had strong bounds on the composite scale, e.g. from the *S*-parameter:

$$
\sim \frac{1}{m_\rho^2} H^\dagger \sigma^i H W^i_{\mu\nu} B^{\mu\nu}
$$

or *S* ≈ *4*π(*v/m*ρ)*2.* This puts the resonance masses at about 3 TeV or above.

 δm_h^2 $\bar{h} \approx$ 9 $\frac{9}{64\pi^2} g^2 m_\rho^2$ $\overline{\rho}$ $\stackrel{>}{_{\sim}}$ $(250 \; \hbox{GeV})^2$ Implies some tuning, e.g. the quadratically divergent *W* loop:

Also via $m_{\rho} \sim 4 \pi f / \sqrt{N}$ it means minimum factor ~3 treelevel tuning of the Higgs potential. $m_\rho\sim 4\pi f/\sqrt{2}$ *N*

COMPOSITE HIGGS COUPLINGS $\left(\begin{array}{c} \text{S} & \text{S} \end{array} \right)$ is the electron than the electronic scale. From the electronic scale. From the electronic scale of \sim e e el est and where we may be likely to see deviations from the SM pattern in the SM pattern in the SM pattern in the future. In the future of the SM pattern in the future of the SM pattern in the SM pattern in the future It is well well well in the SM, such a loop level in the SM, such a loop level in the SM, such as the SM, such a

The lighter the composites, the more they affect Higgs couplings. E.g. coupling to vectors (see e.g. recent Azatov/Galloway review 1212.1380): couplings. Lig. coupling a *h* ! and *h* ! *Z*, and the gluon-fusion production *gg* ! *h*, are particularly sensitive iter the composites, the more they affect \blacksquare π Γ σ coupling to vortors (execution to electronic) the Higgs is a composite Nambu-Goldstone (NG) boson of a new strongly-interacting sector,

$$
a = \frac{g_{VVh}}{g_{VVh^{(\rm SM)}}} = \sqrt{1 - \frac{v^2}{f^2}}.
$$

Civich the Constantian beyond on f this compation of Siven the sparanneler sound sir pans to no de $\frac{1}{2}$ there's no deviation observed. Given the *S*-parameter bound on *f*, this correction ends up at ~6% for $N = 3$ and $m_p = 3$ TeV. So it's not surprising induced by the exchange of new particles with mass much larger than the electroweak scale rie s-parameter bound on J, this correction ent e↵ective Lagrangian at the dimension-6 level has been performed in previous studies [3–5];

as can be seen from the expansion of the expansion of *dia in terms* is the coefficient of pion $\frac{q}{\sqrt{q}}$ LIID IV OF SS. CHOOSE SOOD DASIS. $\sigma_{HW} = m_W^2 (B/H) \sigma (B/H) m_{\mu\nu}$ pions. From the expansion, and defining Interestingly, Goldstone shift symmetry favors larger deviations in Zy than γγ or *gg*. Choose good basis: (Giudice et al. hep-ph/0703164; Montull et al. 1308.0559; Azatov et al. 1308.2676) of Ref. [7], the CP-conserving operators relevant for the *gg*, and *Z* rates are: ² 0 *g* $\frac{1}{2}$ *S* \overline{C} *W* $\frac{ig}{m^2}$ *HB*
*D D*π, Γ 10Η m_V^2 *W* $(D^{\mu}H)^{\dagger} \sigma^{i}(D^{\nu}H)W^{i}_{\mu\nu}$ *d*_H \overline{O} *D*_{*D*}(*O*_{*U*}*U_D*), \overline{O} *A*_Z (27)

A LESSON?

Strongly-interacting new physics predicts a large set of new higher-dimension operators, many of which were already highly constrained. May have a large "footprint" in terms of signals showing up across a number of channels.

Weakly-interacting new physics can predict more localized discrepancies. Because of this, Higgs measurements so far may tell us more *new* information about weaklyinteracting new physics than strongly interacting new physics (which was already quite constrained).

WHY LIGHT TOP PARTNERS? t , is instead different in each case. In this paper we focus on the possibility that $\frac{1}{2}$ the right handed top quark *t^R* is a *SO*(4) singlet belonging to the strong sector, therefore the top $F(A|A|A|A|A|A|A|B\top B\top A B\top B A B\top B A B\top B$ Z *d*5*p p/* + *p*5⁵ + *m* 1 **Some notes on the** *SHuHd* **model**

Elementary/composite mixing for top: $\lambda_L q_L \mathcal{O}_R + \text{h.c.}$ α composite mixing for top: $\lambda_L q_L \mathcal{O}_R + \text{h.c.}$

Puzzles: I. need large top Yukawa; operator of dim 5/2? 2. why a light bound state? linear divergent and more sensitive to the ultraviolet physics. **1 Goals**

(Could have light bound states from anomaly matching: example in hep-ph/0312287, "A Composite Little Higgs Model," by E. Katz, J. Lee, A. Nelson, D. Walker) where *a, b, c, . . .* are coecients expected to be *O*(1), *f* is the decay constant of the -model, while *m* symmetry. Plass terms violate partly, but it's broken by the since of the top*rier masses.* Why a a light buik fermion: (6D: 10D:)
Continues *i* and *f* wik naturalness puzzle $^{\prime}$: 5D termions are unprotected b $\frac{1}{2}$ a monoctor M_{200} to moon, $\frac{1}{2}$ to hout the husband. m ary not be the taking into a count of boundary, σ For the Addition of the flat space correction should still remain. But showed a space correction showed still remain. "Bulk naturalness puzzle": 5D fermions are unprotected by chiral symmetry. Mass terms violate *parity*, but it's broken by heavier masses. Why a light bulk fermion? (6D? 10D?) $\frac{1}{2}$ $\frac{1}{2}$ *S* light bulk termion(Ib $\frac{1}{2}$ *drity*, *D* $\frac{1}{2}$ become $\frac{1}{2}$

✓430 GeV

FERMIONIC TOP PARTNERS 1200 (1.122) 0.120 (1.122) 0.120 (1.122) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123) 0.120 (1.123 IC I CP PAR I

recent survey of models / limits in 1211.5663: de Simone, Matsedonskyi, Rattazzi, Wulzer

rigure 11: Maxmai and minimal bounds on the masses of top partners for $y \in [0.3, 3], c_1 \in [0.3, 3]$ and
 $\zeta \in [0.1, 0.3]$ for the models M4. M1. (left pannel) and M4. M1. (right pannel). Blue and groop bars correspond respectively to high and low values of *y*. Black dashed lines correspond to the exclusions for the reference values $\xi = 0.1, c_1 = 1, y = 1.$ Figure 11: Maxmal and minimal bounds on the masses of top partners for $y \in [0.3, 3]$, $c_1 \in [0.3, 3]$ and $\xi \in [0.1, 0.3]$ for the models $\mathbf{M4}_5$, $\mathbf{M1}_5$ (left pannel) and $\mathbf{M4}_{14}$, $\mathbf{M1}_{14}$ (right pannel). Blue and green bars Figure 2: The typical spectrum of the top partners. $\text{rccone values } \zeta = 0.1$,

 $p(x) = \frac{1}{2}$ elow 1 Tev for tuning: Panico, Redi, Iesi, VVUIzer 1210.7114 Mant helow | Tel/for tuning Want below 1 TeV for tuning: Panico, Redi, Tesi, Wulzer 1210.7114

LITTLE HIGGS

Little Higgs models have an extra symmetry, *naturally* parametrically separating *f* and *v*. EWPT can be protected with *T*-parity (similar to SUSY with *R*-parity).

Here there are generally new *elementary* fermionic top partners. At least 20% tuning (Berger, Hubisz, Perelstein 1205.0013).

Pay a price in model complexity, and still we haven't seen top partners.

SUSY: TREE-LEVEL HIGGS COUPLINGS II. INLE-LEVEL FIIUI T technique of the previous section can be applied also to the Minimal contribution of the Minimal contribu Supersymmetric Standard Model (MSSM)². The only contribution to the quartic potential comes from the

In SUSY have (at least) a 2HDM. Useful way to think about the physics: Gupta, Montull, Riva 1212.5240. Go to **Higgs vev basis**, rather than mass basis. $\frac{1}{2}$ *g*² + *g*⁰ ² to tl *g*² + *g*⁰ ² $\overline{1}$ out the $\mu_{\text{c}} = -\frac{V}{H}$ *n* mass bas

FIG. 1: *The mixing between h and H, induced by the quartic interaction h*³*H, modifies the couplings of h to the* fermion couplings ~ v^2/m_H^2 suppressed. Eigenstate with VEV has SM couplings. Deviations in *EV* has SM couplings. Deviations in

 $c_b \approx 1 - \frac{m_Z}{2m^2} \sin 4\beta \tan \beta$ enhances other branching m_H^2 $\frac{2m_H^2}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ $\frac{m}{\pi}$ normalized with its SM value *ySM f* α *c*, α , *a* MSSM: $c_b \approx 1 - \frac{m_Z^2}{2m^2}$ *Z* $2m_H^2$ $\sin 4\beta \tan \beta$ enhances other branching ratios

TREE-LEVEL 2HDM EFFECTS mixing discussed in the previous paragraph. As mentioned above, this term is maximized by large mixing, LL V LL ZI IDI I LI I LC I J The contributions to and are similar to Eqs. (13,14), with the substitution *m*² *^Z/v*² ! ⁴. In the absence \blacksquare i internettelects that allows the loop e \blacksquare \blacksquare in order to obtain the observed Higgs mass \blacksquare

Even though these are weakly-coupled theories,
 corrections can be very important. Affecting the Higgs coupling to b quarks can dramatically change other branching ratios. In SUSY, can be correlated with $m_h = 125$ GeV. itst are weakly-coupled the Higgs, to and to our predictions can be seizable. Nevertheless such large values of tan are already in tension and a can didition change out for biditioning *ther m*² *h m*² *H* **tes** *.* (29) meaning that, for tan *>* 1, positive (negative) deviations are expected in *c^b* (*ct*). For large tan the modifications in *^c^t* vanish, as usual, while those on *^c^b* asymptote to *^c^b* ¹ ⇡ (176 GeV*/mH*)². This is shown, using the exact expressions from Appendix II, in Fig. 1. Do τ discussed the all τ decrees stop as previous section, t diamialcany change outer pranching orrolated i In principle we could relax the assumption that *H*¹ and *H*² carry equal and opposite *U*(1)*^X* charges. In this 6

ONE-LOOP COUPLINGS: LOW-ENERGY THEOREM \vdash *d*2⇤*SWW* + *h.c.* (2.5) Let's work out the coe⌃cient *c* and then compute the resulting decays. *m^Y* Let's work out the coe⌃cient *c* and then compute the resulting decays. VV-EINERGI IHEUREM In the case, we expect that case, we expect that case of the form: \Box \overline{r} *m^Y* Ĭ. LOW-ENERGY I HEOREM *m^Y* Let's work out the coe⌃cient *c* and then compute the resulting decays. Ω **CONSECCOLLES MENTALES.** Let's work out the coe⌃cient *c* and then compute the resulting decays. J/NAP

The Higgs-gluon-gluon and Higgs-photon-photon couplings are related to beta function coefficients: **L** \overline{a} Life miggs-giuon-giuon and miggs-photon-photo τ be Higgs gluen cluen and Higgs photon photon unction c
1 4*g*2*G^a* $\frac{1}{2}$ T_{S} beta function coe⌃cient. Suppose we have a Lagrangian The His couplings are related to bet

Gauge theory:
$$
\mathcal{L} = -\frac{1}{4g^2} G^a_{\mu\nu} G^{a\mu\nu}
$$

Run from A down to *u*, with an intermediate threshold $\mu < M < \Lambda$ at which the beta function $chanc \ from \ the \ the \ th \ th \ th \ th$ changes from b to $b + \Delta b$. \overline{a} *^µ*⇧*Gaµ*⇧*.* (2.6) Run from Λ down to μ with an intermediate threshold $\mu < M < \Lambda$ at which the

above *M*. Then taking account of that threshold, RG:

RG:

$$
\frac{1}{g^2(\mu)} = \frac{1}{g^2(\Lambda)} + \frac{b}{8\pi^2} \log \frac{\Lambda}{\mu} + \frac{\Delta b}{8\pi^2} \log \frac{\Lambda}{M}
$$

LOW-ENERGY THEOREM with *µ<M<* ⇥, so that the beta function coe⌃cient changes from *b* below *M* to *b* + *b* with *µ<M<* ⇥, so that the beta function coe⌃cient changes from *b* below *M* to *b* + *b*

Suppose the mass threshold is actually a function
of space and time: of space and time: \mathcal{F} be the mass threshold is actually a f Cunnaca the mass throshold $\overline{\mathsf{c}}$ $\frac{1}{2}$ \overline{C} ⁸⌃² log ⇥

 $M \rightarrow M + \delta M(x)$

will lead the spatial to a spatial to a spatial term in the spatial term in the spatial term in the set of the scale \mathcal{F} Then we have a spatially varying gauge coupling: Now, the trick is to allow the threshold *M* to have spatial variation, *M* ⌅ *M* +⇥*M*(*x*), which I hen we have a spatially varying

$$
\frac{1}{g^2(\mu, x)} = \frac{1}{g^2(\mu)} + \frac{\Delta b}{8\pi^2} \log \frac{M}{M(x)} = \frac{1}{g^2(\mu)} - \frac{\Delta b}{8\pi^2} \frac{\delta M(x)}{M}
$$

In particular, if $M(x)$ depends on the Higgs, J $\overline{\Lambda}$ $\overline{\mathcal{U}}$ then we extract a ct an ϵ ⇤*S*(*x*) *m^Y re* coupling: In particular if $M(x)$ depends on the Higgs $M = M(h(x))$ in particular, in $M(x)$ depends on the figgs,. S^{3} , \overline{M} $\overline{}$ $\overline{}$ $\overline{}$ $\binom{n}{k}$ then we extract an effective coupling: In particular, if $M(x)$ depends on the Higgs, $M = M(h(x))$, then we extract an effective coupling:

$$
\frac{\Delta b}{32\pi^2} hG^a_{\mu\nu}G^{a\mu\nu}\frac{\partial \log M(v)}{\partial v}
$$

vo Shitman, Vainshtein, ∂v Shifman, Vainshtein,

STOPS

$$
M_{\tilde{t}}^2 = \begin{pmatrix} \tilde{m}_Q^2 + (y_t^2 + \mathcal{O}(g^2)) v^2 & y_t v \sin \beta X_t \\ y_t v \sin \beta X_t & \tilde{m}_u^2 + (y_t^2 + \mathcal{O}(g^2)) v^2 \end{pmatrix}
$$

Here $X_t = A_t - \mu \cot \beta$, the $O(g^2)$ parts are D-terms I will hereafter ignore, and the key point is that **the Higgs VEV appears in both diagonal and off-diagonal terms.**

For large soft masses: 1 2 $\partial \log \det M^2_{\tilde{\star}}$ \tilde{t} ∂v $\sim y_t m_t$ $\tilde{m}_Q^2 + \tilde{m}_u^2 - X_t^2 \sin^2 \beta$ $\tilde{m}_Q^2 \tilde{m}_u^2 - X_t^2 m_t^2 \sin^2 \beta$

STOPS

Things to note:

$$
\frac{1}{2} \frac{\partial \log \det M_{\tilde{t}}^2}{\partial v} \sim \underbrace{y_t m_t}_{\tilde{m}_Q^2 \tilde{m}_u^2 - X_t^2 m_t^2 \sin^2 \beta}_{\tilde{m}_Q^2 \tilde{m}_u^2 - X_t^2 m_t^2 \sin^2 \beta}
$$

Small numerator factor (for heavy stops): no longer nondecoupling

Minus sign: large mixing leads to opposite-sign couplings

Intuition: in the highly mixed case, larger VEV means more mixing, splitting light and heavy stops more. The light one contributes more, and is pushed lighter, so the overall sign reverses.

DANGER IN LOOPS and including *N* copies with identical couplings, the relevant RGEs read [48, 49] ✓3 *^t* ⁹*g*² ⁴ ⁹*g*² ◆ T, ini
1 ⁺ *^N* Ē

Fermions generically cause Higgs vacuum stability problems (Arkani-Hamed, Blum, D'Agnolo, Fan 1207.4482) *dt* = *yⁿ* $\overline{\Omega}$ \overline{a} *nerically cause* Higg *<u>ys</u> vacult* l. num : $\overline{}$ $\overline{}$ *,* = *y^t* י
ז ג *ne*u, *b*ium, L $\overline{}$ λ gnolo, F 2 Fan I 1 $|2$ *,*

$$
16\pi^2 \frac{d\lambda}{dt} = \lambda \left(24\lambda - 9g_2^2 - \frac{9g_1^2}{5} + 12y_t^2 + 4\mathcal{N} \left(y_n^2 + y_n^{c2} + y^2 + y^{c2} \right) \right) - 2\mathcal{N} \left(y^4 + y^{c4} + y_n^4 + y_n^{c4} \right) - 6y_t^4
$$

+ $\frac{3}{8} \left(2g_2^4 + \left(g_2^2 + \frac{3g_1^2}{5} \right)^2 \right).$ (A.1)

DANGER IN LOOPS

Large deviations from *scalars* in loops are also dangerous:

 \sim -0.005 0.001) (theories) or large negative quartics $\overline{\mathcal{L}}$ t_r a trilinears Large trilinears (e.g. *A*-terms in SUSY both imply *tree-level* instabilities.

Lan have rapid $0.120011700,0.35$ $\sqrt{15}$ Langacker, Segre hep-ph/9602414 Can have rapid tunneling. MR 1208.1765; earlier: Kusenko,

Figure 4: Tree-level potential *V*(*h*, ˜*t ^L*, ˜*tR*) along the subspace ˜*t ^L* = ˜*tR*. We have fixed *mQ* = *mU* = 800 GeV and adjusted *Xhelesson: even though changing sign c* One lesson: even though changing sign of *hGG* amplitude could preserve the rate, theories that do it are usually ruled out Large huy enhancements are c ruled out. Large *hγγ* enhancements are *a priori unlikely*. 1 mass splitting for the spiritual spiritu

h h Higgs potential -μ²|H|²+λ|H|⁴: large quantum corrections to the mass² term. Direct searches constrain them:

$$
\delta m_{H_u}^2 = -\frac{3}{8\pi^2} y_t^2 \left(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + |A_t|^2 \right) \log \frac{\Lambda}{\text{TeV}}.
$$

 \Box Fither the stop is light or Higgs po Either the stop is light, or Higgs potential is finely-tuned.

 τ to build the shample of $(1 + 1/\mathsf{D})$ T_{N} iwo stops (LH/KH), one spottom Two stops (LH/RH), one sbottom (LH) should all be light!

THE DATA SO FAR

Azatov & Galloway, fit in 1212.1380 (updated post-Moriond)

Consistent with SM! Puts bounds on new physics.

STOP BOUNDS FROM HIGGS

A pair of stop masses is associated with a maximum X_t (property of 2x2 matrices: can't have equal eigenvalues if nonzero off-diagonal term).

Fitting data with light stops requires a *minimum* X_t . Part of parameter space is simply ruled out; more is tuned, even running from only 10 TeV.

Even without direct searches, know stop/Higgs tuned by factor ~ 5 or more. Impact of NⁿLO K-factors?

A "NO-HIDE" THEOREM?

Model builders can build increasingly byzantine constructions to hide natural physics from direct searches, but *anything enforcing naturalness must couple to the Higgs*.

Craig, Englert, McCullough 1305.5251:

RARE HIGGS DECAYS

 0.0 $($ $($ $)$ $($ Raidal, Strumia 1303.3570. 5
J Most familiar: invisible Higgs. 15 20 Invisible Higgs BR non-SM²⁰(e.g. "hidden valley"), $SM+BR_{inv}+$ $+BR_{gg}+BR_{\gamma\gamma}$ Giardino, Kannike, Masina, DM detection. Right: Complementary to direct $35 \,$ Xenon100 0 10 20 30 40 50 60 70 10^{-12} 10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} DM mass in GeV ${\rm Spin}$ -Independent $\sigma_{\rm SI}$ in pb scalar fermion ector One exciting result of the relatively small SM Higgs couplings is that the Higgs could have a large width into even with small couplings.

Figure 9: Left: *fits to the invisible Higgs boson branching fraction under the two di*↵*erent* pseudoscalars, exotic fermions.... Search broadly! Many other possibilities: e.g. decays to dark photons, light

the universal fit (dotted curves). Right*: upper limit on the spin-independent DM cross section* See Stefania Gori's talk for more.

CONCLUSIONS

Higgs couplings provide a very interesting probe of new physics, complementary to direct searches. Directly probe naturalness.

Example: some light stops may not be excluded by direct searches if they decay in unusual ways, but they *are* excluded because they change *ggH* coupling.

Strongly-coupled models were already pushed by EWPT into a range where large deviations in Higgs properties are not expected. But Higgs offers a new set of EWPT observables.

The Higgs completes the SM; perhaps it will also be a window to beyond the SM.

HIGGS COUPLINGS FOR NATURAL MODELS

Two effects we've discussed impact the Higgs production and decay:

Mixing alters *bb* rate, thus changing all other smaller branching ratios. No signal: bad for λSUSY. \overline{a}

Loops alter *gg* and γγ couplings. No signal: bad for stops.

"Typically," in natural models, would like to have seen effects \sim 20%.

WHAT NEXT?

It's interesting that very conservative and general arguments already put most of our favorite models at *at least* ~20% tuning.

For composite Higgs, the *S*-parameter alone does approximately that.

For SUSY, absence of large stop loop corrections to Higgs properties also does approximately that.

In most specific models, combining constraints (e.g. direct searches) requires a much worse tuning!

STOP BOUNDS

1

GLUINO TO STOP BOUNDS

Great progress here. We have many complementary channels and the bounds are one of the biggest worries for natural SUSY.

But: Dirac gluino could be heavier and natural....

NATURAL HIDDEN SUSY?

This "split generations" scenario is increasingly constrained by stop & sbottom searches and has tension with flavor. But natural SUSY doesn't *require* splitting the squark generations if they're hidden.

Some ways to hide superpartners:

- decay through RPV
- decay through hidden valley (large multiplicity, less phase space for missing momentum)
- decay through lepton jets (special case of hidden valley) - decay through stealth SUSY (another special case, with a nearly-supersymmetric hidden sector) 26

STOPS WITH *R*-PARITY VIOLATION

Some experimental results are already appearing, e.g. CMS 1306.6643 with LQD operator (muon/top/bottom) **5** At 95% CL we exclude pair production of colorons with mass m*^C* in the range 250 *< m*^C *<* 700.00 10 vyitii L \sqrt{D} ope

WHICH RPV?

RPV is a huge space of models. The "MFV RPV" framework (Csaki, Grossman, Heidenreich 1111.1239) and the "Bilinear RPV" case (only *LH* operators; Graham, Kaplan, Rajendran, Saraswat 1204.6038) seem like two of the most reasonable to me. Long lifetimes evade some bounds?

Multi-jet resonances (possibly top+jets) as a signal of left-right mass insertion. In this case, the partial widths (˜*b^L* ! *^u*¯*ⁱ* ¯ naturalness?

RPV STOPS

STOPS IN STEALTH SUSY

Unlike the minimal "stealthy stop" scenario, $\tilde{t} \to t \tilde{\chi}^0$ with the stop mass just above the top mass, here we mean a cascade through a stealthy "hidden sector." An Observation

Inside the hidden sector, a near-degeneracy of *R*odd and *R*-even particles (due to approximate SUSY) leads to small missing momentum.

STOPS IN STEALTH SUSY **1 Goals**

In stealth SUSY models, the signal of stops might be tops + extra jets (possibly with weak bosons). Also 1st, 2nd gen simplified models. The first part of this step is to understand the mass spectrum and decays for j ust higgsinos and decays the singlet finance singlet finance to an among the main to an squarks: many-jet events, possibly with weak bosons.

¹ !*S*˜⁺ *^h*? (Presumably is suppressed)?

¹ !*S*˜+*^Z* and *^H*˜ ⁰

• What are the branching ratios for *^H*˜ ⁰