Higgs Boson Exempt No-Scale Supersymmetry

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W/ Jason Evans, David Morrissey

SUSY, remembering first impressions

Condensed Matter physicist at beginning of grad school.
Heard talk about the SM Higgs boson -- ridiculous!!

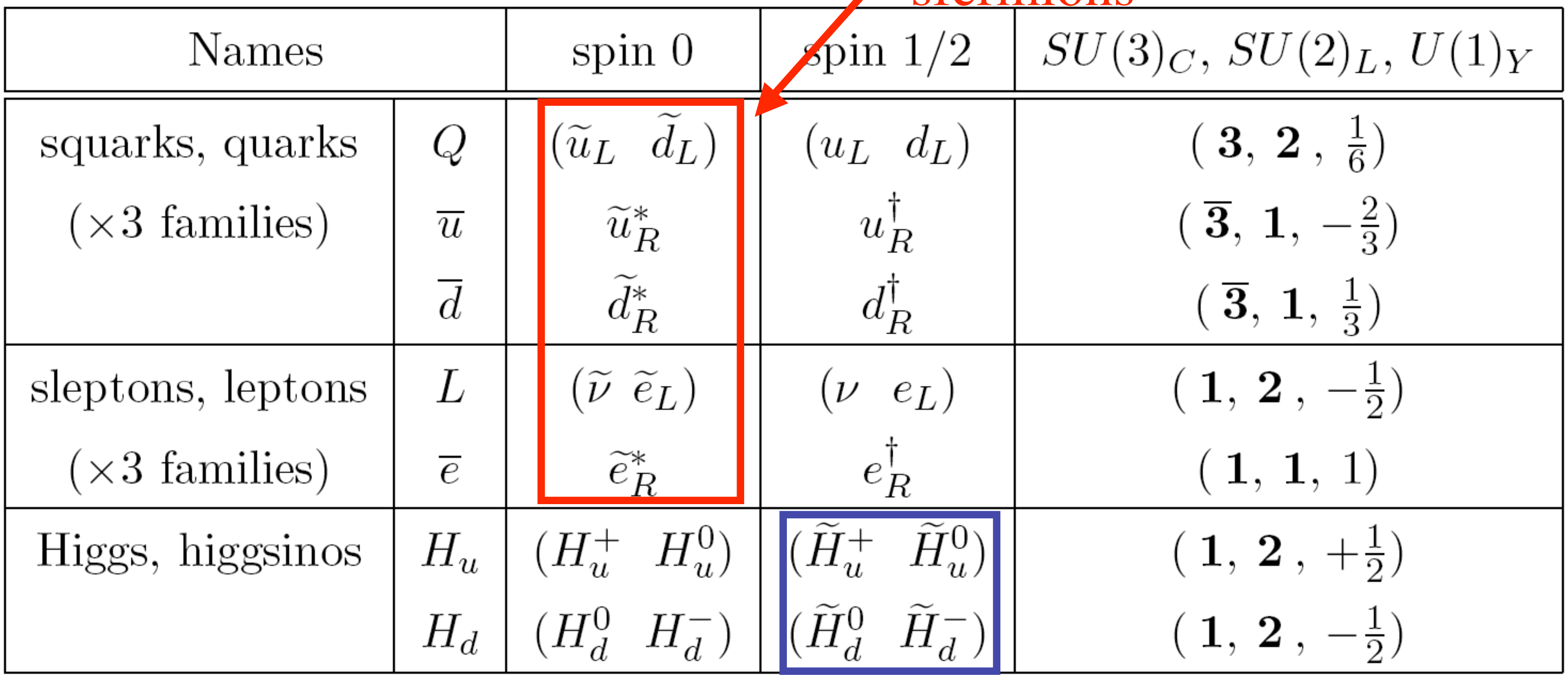
"Gordy Kane has ideas about the Higgs boson" --> talk to him

Supersymmetry: grand unification of particles, gauge coupling unification, Higgs(es) are stable to corrections, radiative symmetry breaking, interesting mathematics, string theory relevance, viable dark matter candidate, predictions possible for new phenomena, etc.

Wow!

Minimal Supersymmetric Standard Model
Particle Content

“sfermions”



Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks (×3 families)	Q	$(\widetilde{u}_L \ \ \widetilde{d}_L)$	$(u_L \ \ d_L)$	$(\, \mathbf{3}, \ \mathbf{2}\, , \ \frac{1}{6})$
	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\, \overline{\mathbf{3}}, \ \mathbf{1}, \ -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\, \overline{\mathbf{3}}, \ \mathbf{1}, \ \frac{1}{3})$
sleptons, leptons (×3 families)	L	$(\widetilde{\nu} \ \ \widetilde{e}_L)$	$(\nu \ \ e_L)$	$(\, \mathbf{1}, \ \mathbf{2}\, , \ -\frac{1}{2})$
	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\, \mathbf{1}, \ \mathbf{1}, \ 1)$
Higgs, higgsinos	H_u	$(H_u^+ \ \ H_u^0)$	$(\widetilde{H}_u^+ \ \ \widetilde{H}_u^0)$	$(\, \mathbf{1}, \ \mathbf{2}\, , \ +\frac{1}{2})$
	H_d	$(H_d^0 \ \ H_d^-)$	$(\widetilde{H}_d^0 \ \ \widetilde{H}_d^-)$	$(\, \mathbf{1}, \ \mathbf{2}\, , \ -\frac{1}{2})$

Martin, hep-ph/9709356

“Higgsinos”

Also, spin 1/2 superpartners (“gauginos”) to Gauge bosons gluon, photon, W/Z.

Scale of Superpartners

Supersymmetry helps stabilize the weak scale.

$$\frac{1}{2}m_Z^2 + \mu^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1}$$

LHS ~ Z-mass and RHS ~ Tens of TeV.

But what is too heavy?

Gordy’s Response (21 years ago)

“We emphasize that the solution to the naturalness (fine-tuning) problem necessarily predicts that new physical phenomena must exist at a scale of $m_W/g \sim O(1\ \text{TeV})$ or below. In the case of supersymmetry, this new physics consists of a spectrum of new supersymmetric particles (partners of the ordinary particles) which have masses no greater than about 1 TeV and in some cases may be substantially lighter.”

Haber, Kane, Physics Reports 117, 75 (1985), quote from p. 82

Challenges for Low-Energy SUSY

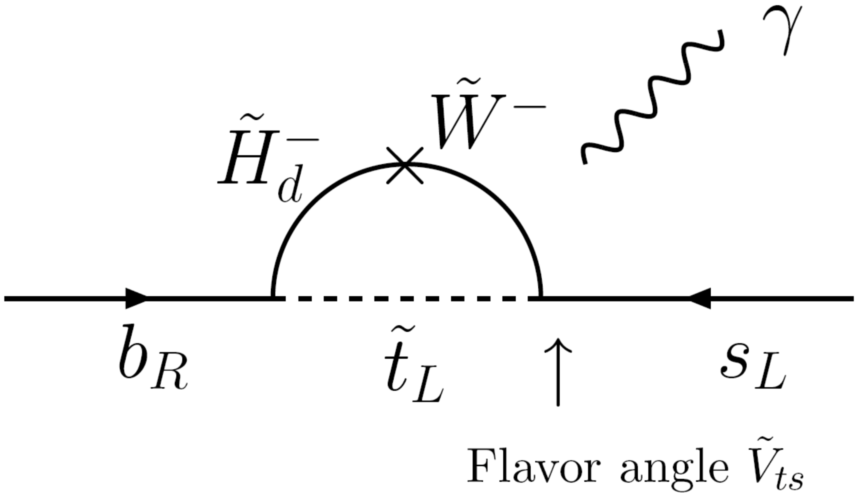
Throw a dart into Minimal SUSY parameter space,
And what do you get?

Observable predictions would be wildly
Incompatible with experiment.

Briefly review these challenges ….

Flavor Changing Neutral Currents

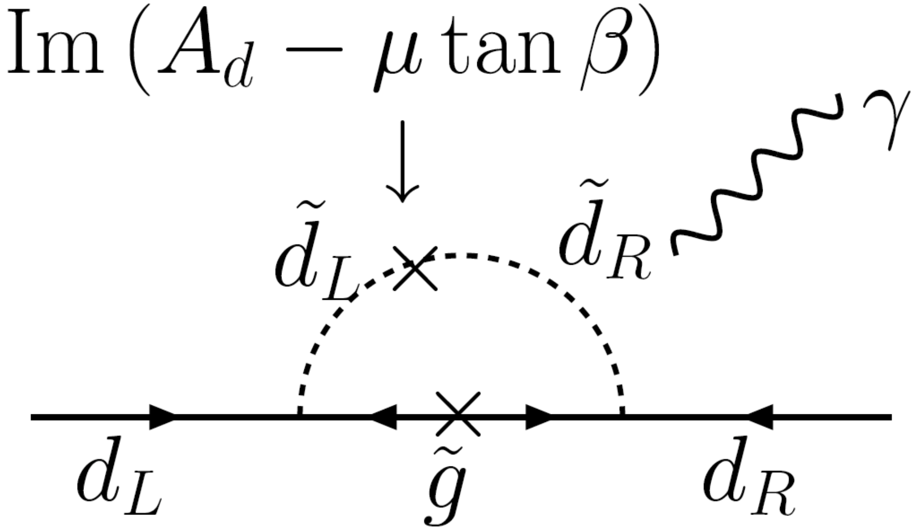
Random superpartner masses and mixing angles would generate FCNC far beyond what is measured:



Large unless universal scalar masses (or scalar masses heavy)

CP Violation

Supersymmetry has many new sources of CP violation:



Large unless CP angle small (or scalar masses heavy)

Higgs boson mass

In minimal supersymmetry the lightest Higgs mass is computable:

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{\tilde{m}_t^2}{m_t^2} + \cdots$$

Tree-level value is bounded by $m_Z = 91\,\mathrm{GeV}$. Current lower limit on Higgs boson mass is $114\,\mathrm{GeV}$. Thus, we need $\sim (70\,\mathrm{GeV})^2$ contribution from quantum correction.

Need $\tilde{m}_t \gtrsim 5\,\mathrm{TeV}(0.8\,\mathrm{TeV})$ for $\tan\beta = 2(30)$

Log-sensitivity keeps m_h below the Precision EW bound (~ 200 GeV)

Where we are at

Supersymmetry

Eliminating bad things:

1. FCNC
2. Proton decay strains
3. CP Violation
4. Too light Higgs mass

Preserving good things:

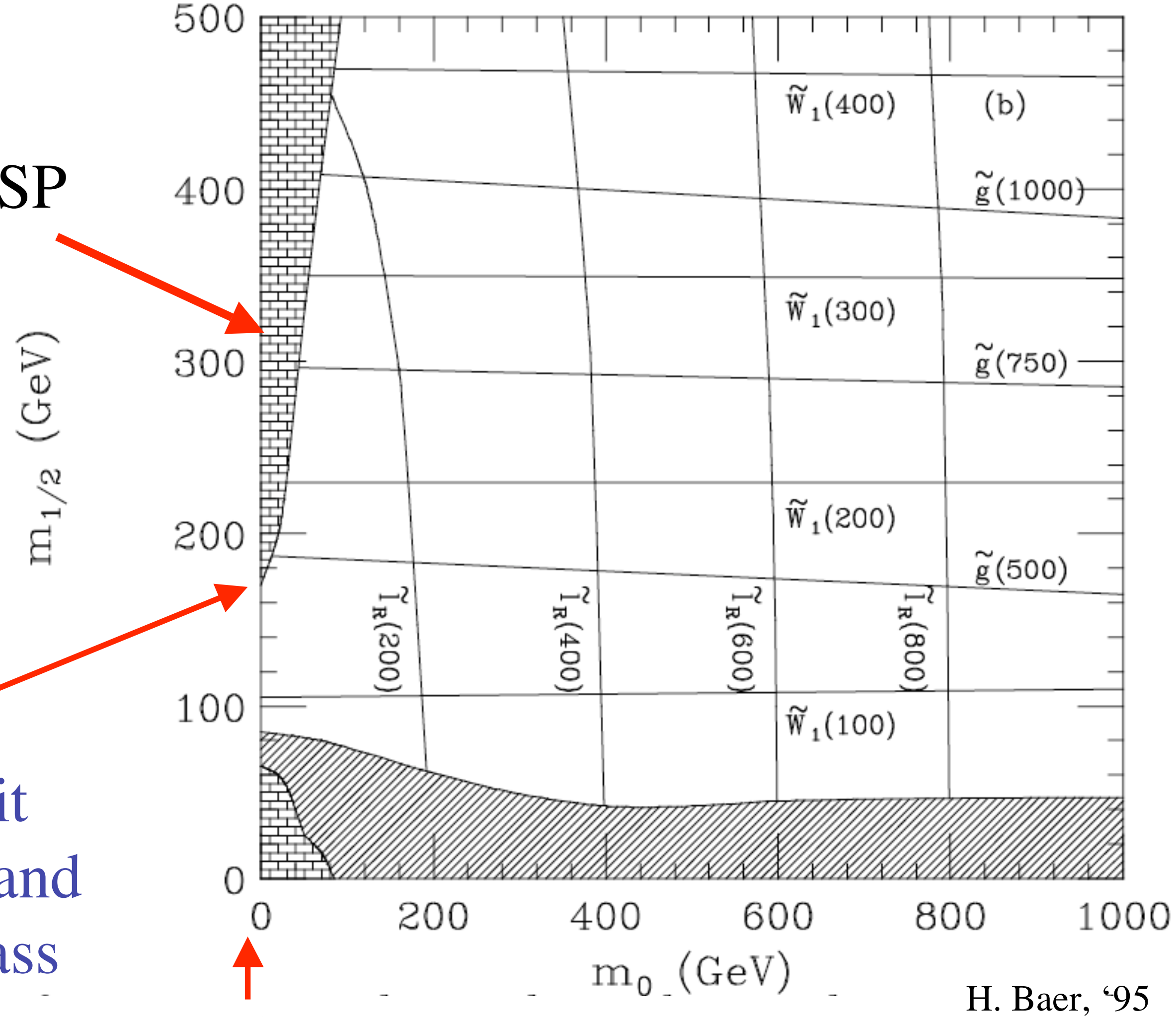
- SUSY Naturalness
- Light Higgs prediction
- Gauge Coupling Unification
- Dark Matter

Two Approaches:

“Split Supersymmetry”:
Scalars are very heavy and
solve FCNC, CP violation,
and too light Higgs problem, etc.

“Higgs-Exempt No-Scale”:
‘Zero mass’ scalars solve FCNC,
Heavy-enough superpartners for
Higgs problem, etc.

What’s wrong with no-scale supersymmetry?



Charged LSP

Upper limit on $m_{1/2}$ which leads to upper limit on superpartners, and too light Higgs mass

No scale

H. Baer, ‘95

Higgs-exempt No Scale

Goal is to increase the $m_{1/2}$ which then can increase Superpartner masses, and can increase Higgs mass.

FCNC under control if slepton,squarks mass = 0

Exempt the Higgs bosons from no scale constraint.

Relevant Equations

The scalar RGE equations with non-universal soft masses:

$$(4\pi)^2 \frac{dm_i^2}{dt} \simeq X_i - 8 \sum_a C_i^a \, g_a^2 \, |M_a|^2 + \frac{6}{5} \, g_1^2 \, Y_i \, S$$

$$S = (m_{H_u}^2 - m_{H_d}^2) + tr_F(m_Q^2 - 2m_U^2 + m_E^2 + m_D^2 - m_L^2)$$

This induces a potentially significant shift in masses:

$$\Delta m_i^2 = -\frac{Y_i}{11} \left[1 - \left(\frac{g_1}{g_{GUT}} \right)^2 \right] S_{GUT} \simeq -(0.052) \, Y_i \, S_{GUT}$$

Some numbers

Compare gaugino masses …

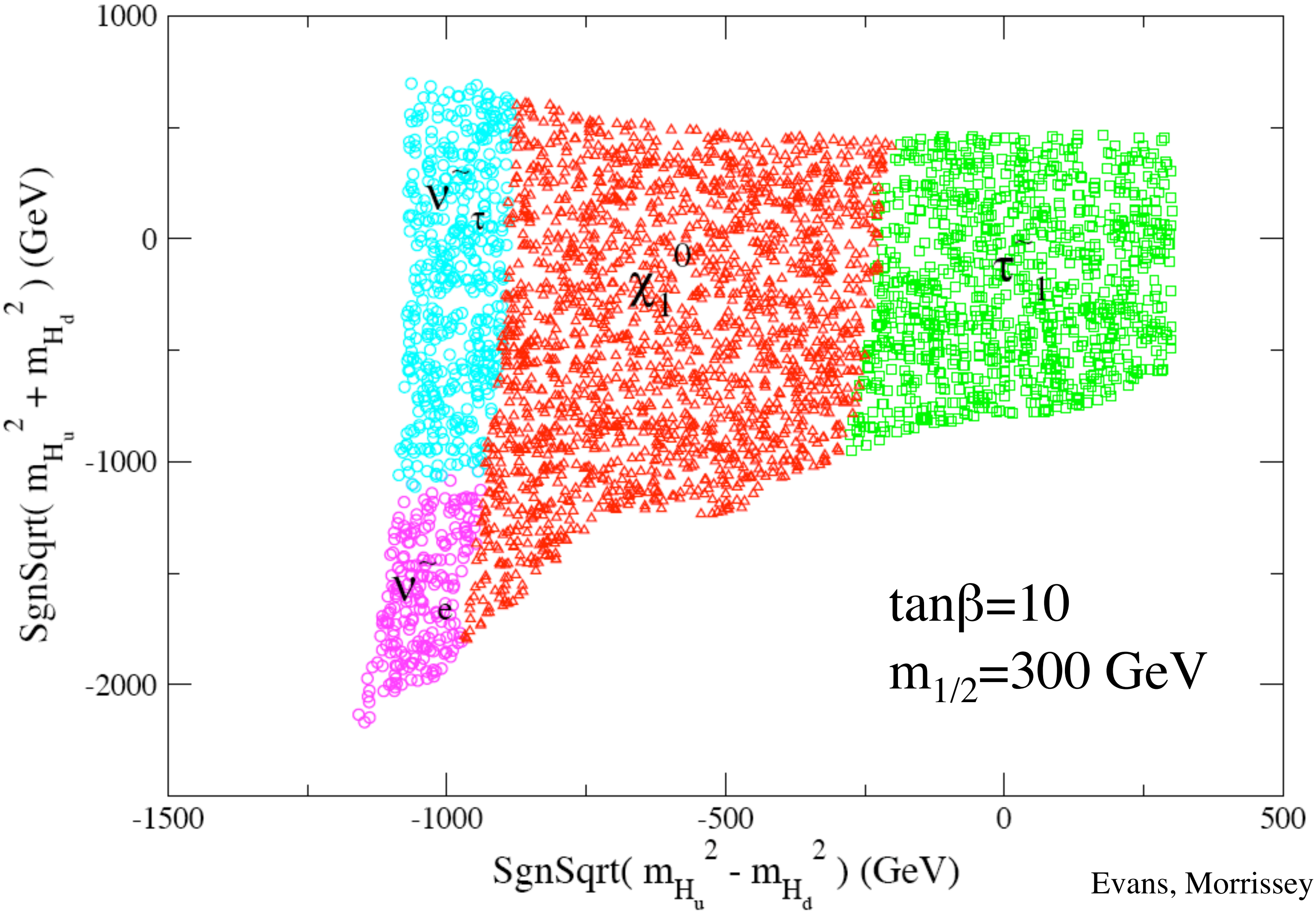
$$M_1 \simeq (0.43)\, M_{1/2}, \quad M_2 \simeq (0.83)\, M_{1/2}, \quad M_3 \simeq (2.6)\, M_{1/2}$$

With slepton masses (negative S helps lift mE):

$$\begin{aligned} m_L^2 &\simeq \left[(0.68)\, M_{1/2}\right]^2 + \frac{1}{2}(0.052)\, S_{GUT} \\ m_E^2 &\simeq \left[(0.39)\, M_{1/2}\right]^2 - (0.052)\, S_{GUT}. \end{aligned}$$

$$S_{GUT} = (m_{H_u}^2 - m_{H_d}^2)$$

LSP in Higgs-exempt No-Scale



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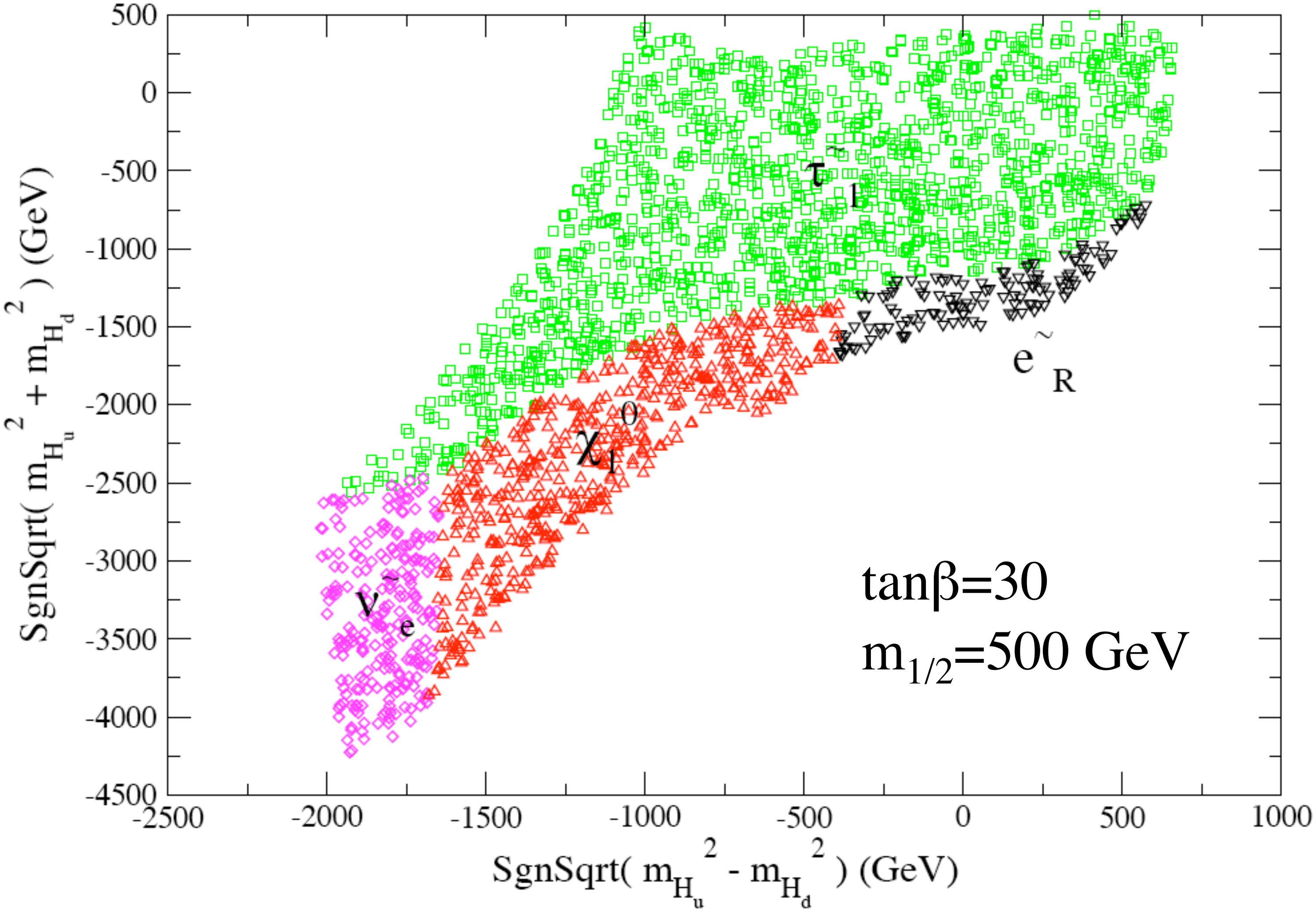
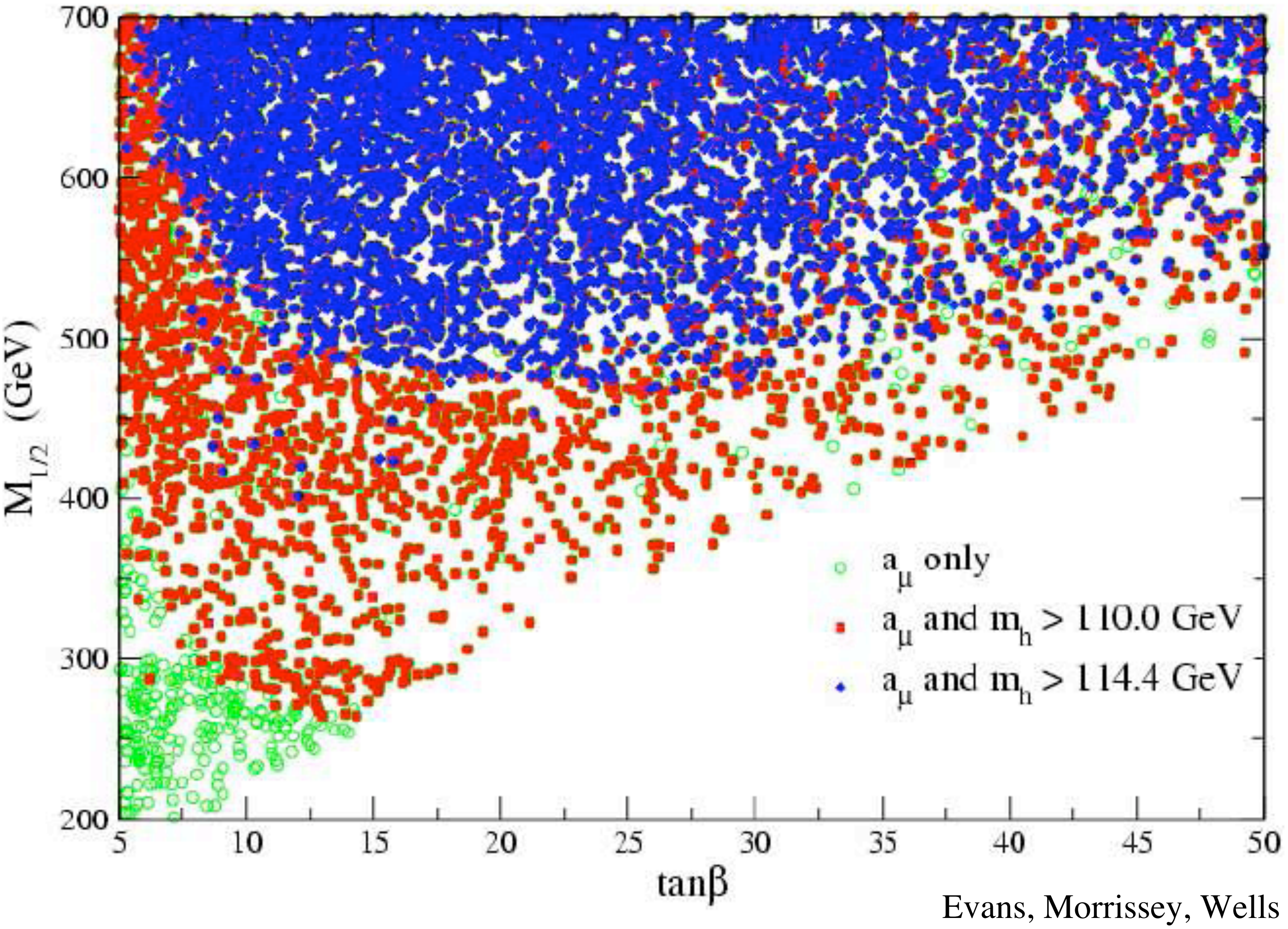
LSP with higher tanβ





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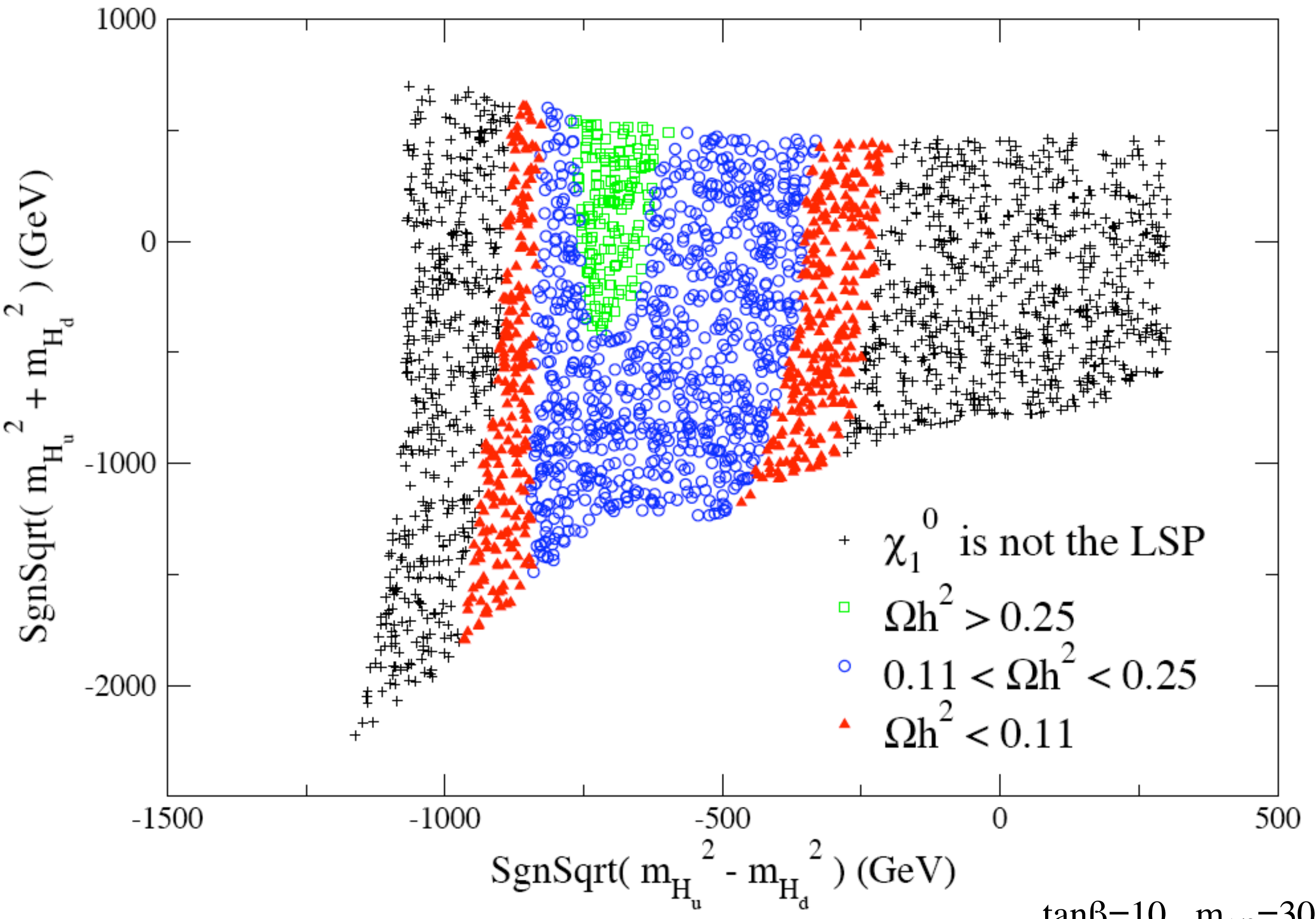
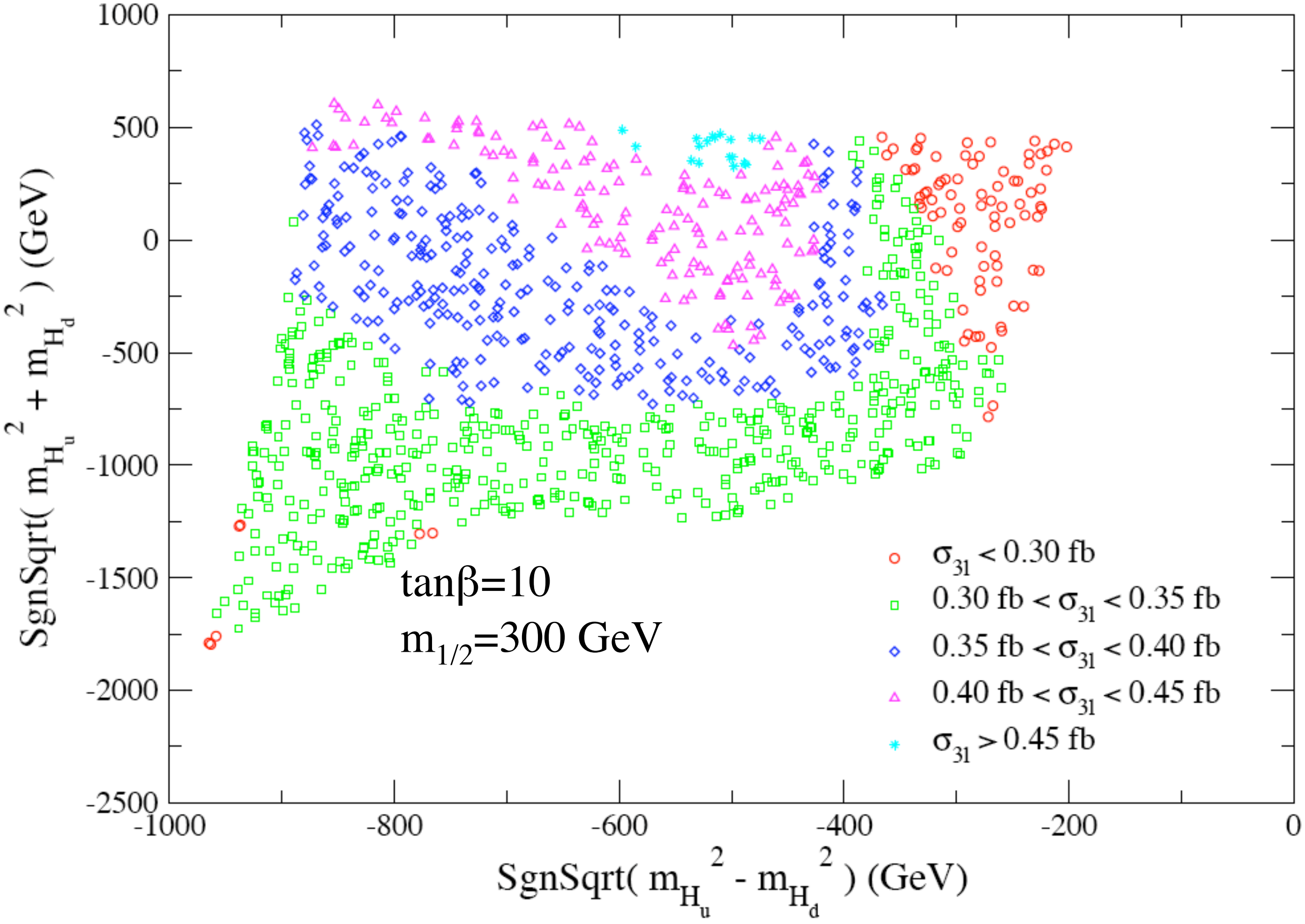
Scatter plot in the $M_{1/2} - \tan\beta$ plane of solutions that respect the bounds of $\Delta a_\mu^{SUSY} < 50 \times 10^{-10}$ and $m_h > 114.4\,\mathrm{GeV}$. Due to uncertainty in the top quark mass, and the theoretical uncertainty in the computation of m_h, a more conservative constraint on this theoretically computed value of m_h is $110\,\mathrm{GeV}$, which is also shown in the figure.

Dark Matter Relic Abundance



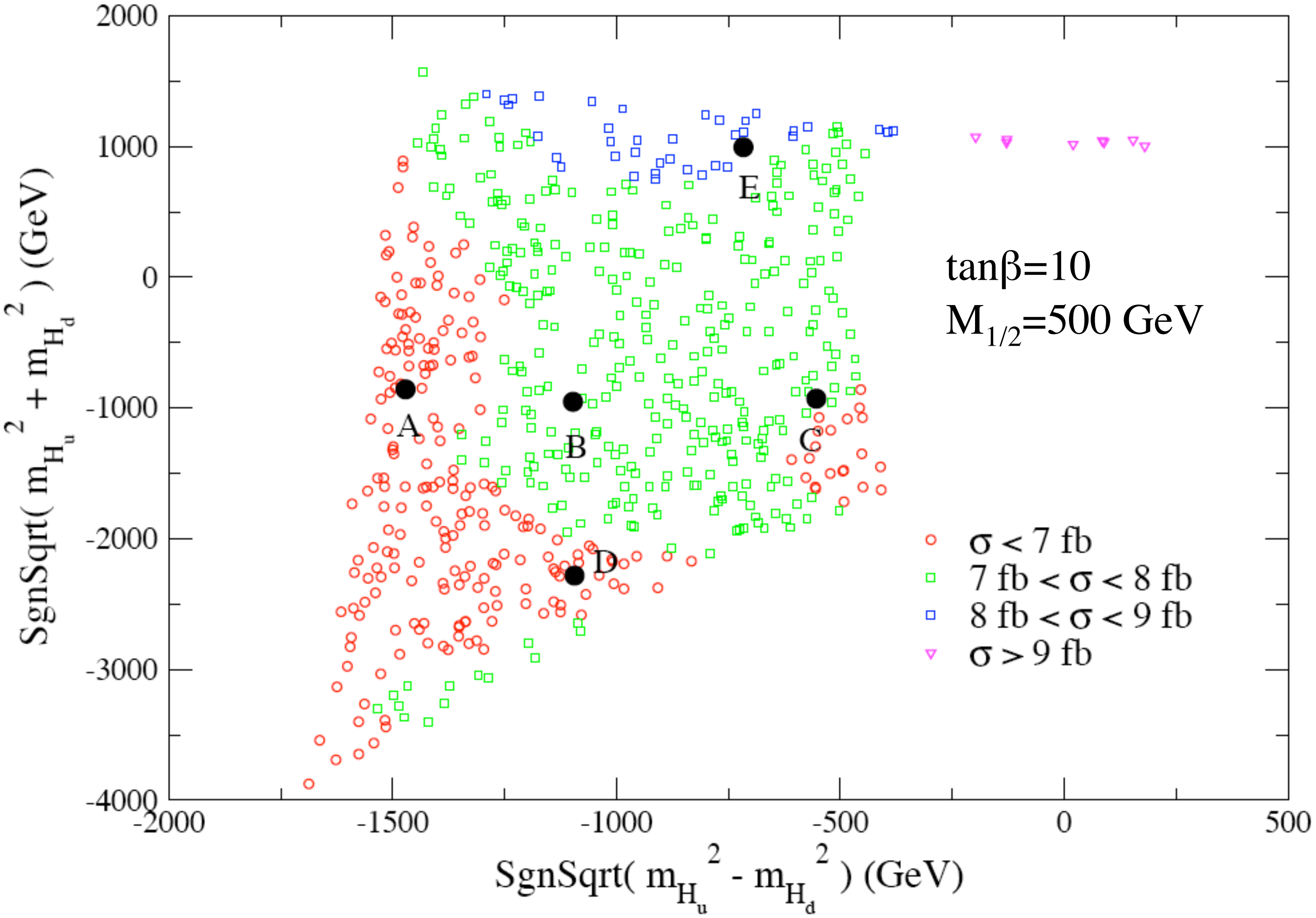
$\tan\beta=10$, $m_{1/2}=300$ GeV

Tevatron 3l Signal



3 leptons plus missing energy. After cuts, 0.49 fb background. Marginal to find HENS scenario at Tevatron with 10 fb^{-1}

LHC 3l Signal



3 leptons plus missing energy. After cuts, 0.1 fb background. For this value of $M_{1/2}$ it is promising at LHC with 10 fb^{-1}

Gordy-Inspired Conclusions

Experiment and theory together are key

We develop meaningful/useful/deeper theories to explain
-- Gordy reminds us there is a high bar for this

Experiment will help us converge: electroweak symmetry breaking, dark matter, etc. largely connected to susy breaking, and susy breaking may clarify the high-scale theory and vice-versa.

One view: SUSY good bets are “Split” (heavy scalars) and “Splat” (zero mass scalars). Lots of fun experiment and theory to come.