Supersymmetry Without Prejudice

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SUSY Without Prejudice

This talk is based on

- JHEP 0902:023,2009/ arXiv:0812.0980 [hep-ph]
- arXiv:0903.4409 [hep-ph]
- Works in progress.

Work by C. F. Berger, R. C. Cotta, J. G. Cogan, JSG, J. L. Hewett, T. G. Rizzo

The Opposite of Model Building

What better way to end a parallel session on model building, than with a project that is, in some ways, the opposite of model building?

Model Building: Propose a new model to address outstanding theoretical, observational, or experimental issues.

Here:

- Take an old, oft-studied model (in our case, the MSSM) with a large parameter space.
- Examine a large number of parameter points (models) to see if they satisfy existing theoretical, observational, or experimental constraints.
- Obtain a large set of such models and study them.

Why?

- Even the R-parity conserving MSSM has over 100 parameters.
- Raises the question of how well have we explored the MSSM.
- Generally, to avoid this issue one limits one's analyses to a specific SUSY breaking scenario(s) such as mSUGRA, GMSB, AMSB, etc. This reduces the number of parameters one needs to consider.
- But how well do any of these scenarios reflect the true breadth of the MSSM??
- Do we really know the MSSM as well as we think??

Parameter Space

- Unfortunately, it is impractical to scan over 100 parameters.
- Assume
  - CP conservation
  - Minimal Flavor Violation
  - 1st and 2nd generation sfermion masses are degenerate.
  - 1st and 2nd generation trilinear couplings negligible (so can set to zero)
- End up with the **pMSSM** (phenomenological MSSM).

The pMSSM

- 19 Parameters
  - Gaugino masses: M_1, M_2, M_3
  - Sfermion masses: $m_{q1,2}, m_{u1,2}, m_{d1,2}, m_{l1,2}, m_{e1,2}, m_{q3}, m_{u3}, m_{d3}, m_{l3}, m_{e3}$.
  - 3^{rd} generation trilinears: A_t, A_b, A_τ
  - Higgs/ Higgsino parameters: $\mu, m_A, \tan\beta$
- **Notes:** All parameters specified $\sim$ the weak scale. Gauge unification is not assumed.

Parameter Ranges

Flat Priors 10^7 points

$$100\,\mathrm{GeV} \le m_{\tilde{f}} \le 1\,\mathrm{TeV}\,,$$
$$50\,\mathrm{GeV} \le |M_{1,2},\mu| \le 1\,\mathrm{TeV}\,,$$
$$100\,\mathrm{GeV} \le M_3 \le 1\,\mathrm{TeV}\,,$$
$$|A_{b,t,\tau}| \le 1\,\mathrm{TeV}\,,$$
$$1 \le \tan\beta \le 50\,,$$
$$43.5\,\mathrm{GeV} \le m_A \le 1\,\mathrm{TeV}\,.$$

Log Priors 2×10^6 points

$$100\,\mathrm{GeV} \le m_{\tilde{f}} \le 3\,\mathrm{TeV}\,,$$
$$10\,\mathrm{GeV} \le |M_{1,2},\mu| \le 3\,\mathrm{TeV}\,,$$
$$100\,\mathrm{GeV} \le M_3 \le 3\,\mathrm{TeV}\,,$$
$$10\,\mathrm{GeV} \le |A_{b,t,\tau}| \le 3\,\mathrm{TeV}\,,$$
$$1 \le \tan\beta \le 60\,,$$
$$43.5\,\mathrm{GeV} \le m_A \le 3\,\mathrm{TeV}\,.$$

We take SM parameters as given.

Procedure

For each parameter point, we calculate the SUSY spectrum using SuSpect (as interfaced by micrOMEGAs for convenience in calculating other observables).

We then apply the following constraints...

Constraints

- LSP is lightest neutralino.
- No tachyons, CCB vacua.
- Higgs potential bounded from below.
- LSP relic density does not overclose universe, but we **DO NOT** demand that the LSP be the dominant component of the dark matter (e.g. axions could be dominant dark matter species).
- Sparticles evade direct detection, esp. at LEP.
- Contribution to invisible width of the Z less than 2 MeV (LEP).

Constraints

- $-0.0007 < \Delta\rho < 0.0026$ (PDG '08).
- $b \to s\gamma$: branching fraction in $(2.5 - 4.1) \times 10^{-4}$ (Combining results from HFAG, Misiak et al., Becher & Neubert).
- $B \to \mu\mu$: BF $\leq 4.5 \times 10^{-8}$ (CDF/ D0 combined).
- SUSY contribution to muon $g-2$: $(-10 \leq (g-2)_\mu \leq 40) \times 10^{-10}$ Wide range to accommodate current tension between theoretical and experimental values. These first 4 observables are calculated with micrOMEGAs.
- $B \to \tau\nu$: $(55 - 227) \times 10^{-6}$ (HFAG, ICHEP08). Our calculation of this quantity followed Isidori and Paradisi and Erikson, Mamoudi and Stal.
- Meson-Antimeson Mixing : Constrains 1st/3rd sfermion mass ratios to be in the range $0.2 < R < 5$ in MFV context. (We implement this constraint in choosing parameter points).

LEP Higgs Constraints

Implement LEP constraints on Higgs sector by using **hdecay**, as interfaced to SUSY-HIT, to calculate cross section times branching ratio to given final states in the models, compare this with LEP bounds.

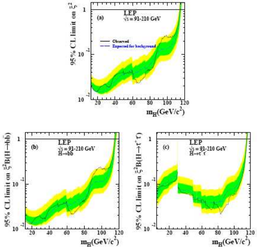


Figure 1: *The 95% c.l. upper bound on the coupling ratio $\xi^2 = (g_{HZZ}/g^{SM}_{HZZ})^2$ (see text). The dark (green) and light (yellow) shaded bands around the median expected line correspond to the 68% and 95% probability bands. The horizontal lines correspond to the Standard Model coupling. (a): For Higgs boson decays predicted by the Standard Model; (b): for the Higgs boson decaying exclusively into $b\bar{b}$ and (c): into $\tau^+\tau^-$ pairs.*

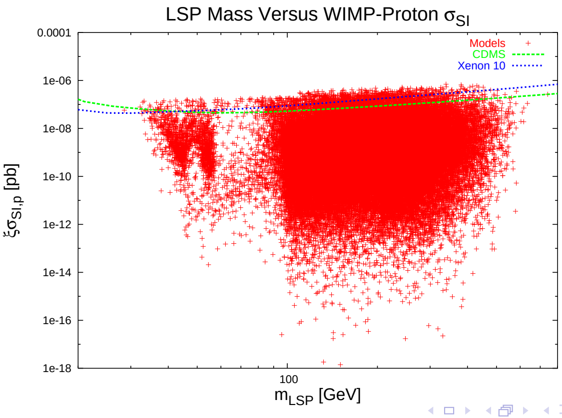
Figure 1 of hep-ex/0602042 from "Search for Neutral MSSM Higgs Bosons at LEP" by the LEP Working Group for Higgs Boson Searches.

Tevatron Constraints

- Tevatron has ruled out some of the $M_A/\tan\beta$ plane; we implement this.
- We also implement the D0 jet plus missing energy constraints by using PGS, Prospino, and SUSY-HIT to simulate Tevatron events for each of our models.
- We implement the analogous CDF constraints on trilepton events, in an analagous manner.
- We also implement D0 constraints on heavy charged particles, especially charginos. This is a very important constraint, as we shall see later.

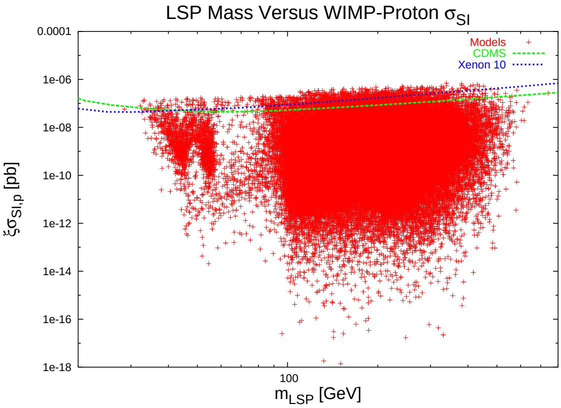
Direct Detection Constraints/ Results

We also use micrOMEGAs to calculate the spin-independent and spin-dependent WIMP-proton and WIMP-neutron cross sections and implement bounds on WIMP-nucleon cross section, in particular (for our LSP mass range) from XENON10 and CDMS.



Direct Detection Constraints/ Results

- Allowed for factor of 4 uncertainty in cross section.
- Cross section scaled to LSP fraction of DM.
- Large range of WIMP-nucleon cross sections.



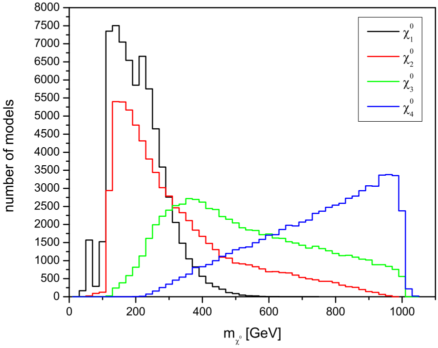
Results

- We find that ∼68,000 models out of the 10,000,000 flat prior points chosen satisfy all existing constraints.
- For our logarithmic priors, ∼2000 models out of 2,000,000 satisfy all constraints.

Results: The LSP

The LSPs in our set are relatively light; most are between 100 and 400 GeV.

The distribution of all 4 neutralino masses for the ∼68,000 flat prior models is shown below.



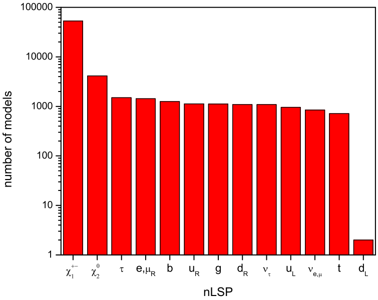
Results: The LSP

A plurality of the models have an LSP which is either nearly pure Higgsino or mostly Higgsino. There are more models with LSPs which have $|Z_{12}|^2 > 0.8$ than with $|Z_{11}|^2 > 0.8$.

LSP Type	Definition	Fraction of Models
Bino	$|Z_{11}|^2 > 0.95$	0.14
Mostly Bino	$0.8 < |Z_{11}|^2 \leq 0.95$	0.03
Wino	$|Z_{12}|^2 > 0.95$	0.14
Mostly Wino	$0.8 < |Z_{12}|^2 \leq 0.95$	0.09
Higgsino	$|Z_{13}|^2 + |Z_{14}|^2 > 0.95$	0.32
Mostly Higgsino	$0.8 < |Z_{13}|^2 + |Z_{14}|^2 \leq 0.95$	0.12
All other models		0.15

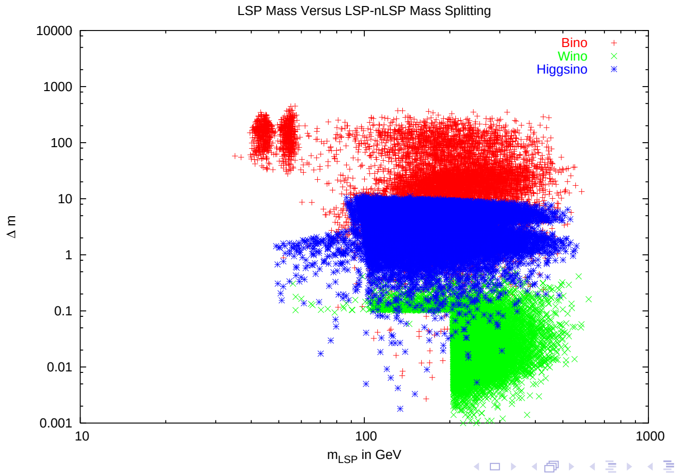
Results: nLSP Identities, nLSP-LSP Mass Splitting

Not surprisingly, given the number of models with Higgsino or Wino LSPs, in many of the models the nLSP is a chargino or a neutralino. However, there are 11 other species of sparticles which are the nLSP in at least one of the models.



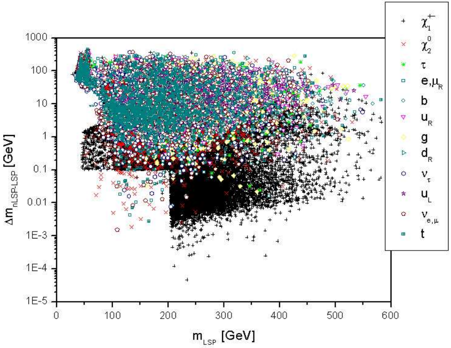
Results: nLSP Identities, nLSP-LSP Mass Splitting

LSP type strongly correlated with nLSP-LSP mass splitting, but there are also accidental degeneracies.



Results: nLSP Identities, nLSP-LSP Mass Splitting

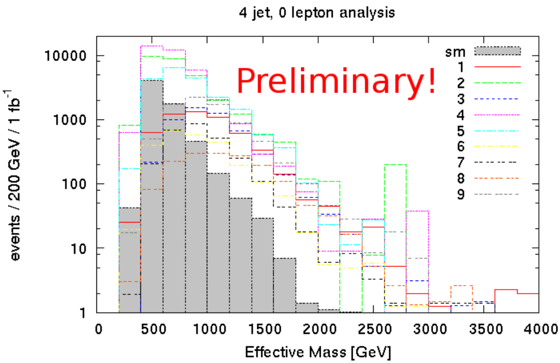
In general nLSP-LSP mass splitting is relatively small; over 80% of the models have $m_{\mathrm{nLSP}} - m_{\mathrm{LSP}} < 10$ GeV.



Note the lower left-hand corner square where models with chargino nLSP have been eliminated by the Tevatron stable chargino search.

Work In Progress

Working on determining the ATLAS signatures of the models that survive constraints (following SUSY chapter of 0901.0512). Using PGS for fast detector simulation, SUSY-HIT for decay table, Prospino for K-factors.



We are also working on understanding direct and indirect detection properties of LSP DM in the model sets.

Conclusions

- A large set of models (parameter points in pMSSM space) have been generated which satisfy existing theoretical, experimental, and observational constraints.
- Studying these models will give insight into unexplored corners of the MSSM.
- Studies of dark matter (direct and indirect detection) and LHC signatures of these models are under way.