Supersymmetry Without Prejudice at the LHC

Jamie Gainer
ANL / Northwestern

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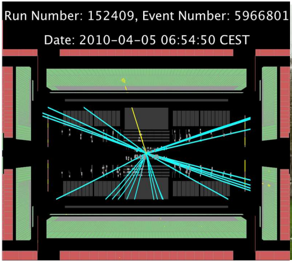
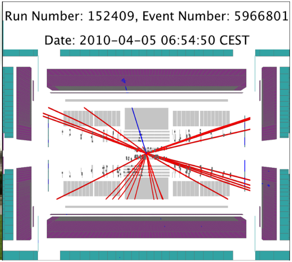


PHENO 10: LHC Decade!

- **SUSY Scan**:
  JHEP 0902:023,2009/ arXiv:0812.0980 [hep-ph].
  (Berger, JG, Hewett, Rizzo.)

- **LHC Signatures**:
  arxiv:1005.ASAP [hep-ph].
  (Conley, JG, Hewett, Le, Rizzo.)
  Main work discussed in this talk.

- **Dark Matter**:
  arxiv:1005.ASAP [hep-ph].
  (Conley, Cotta, JG, Hewett, Rizzo.)
  See Randy's Talk Tomorrow.

- The MSSM is difficult to study in full generality due to the large number of soft SUSY breaking parameters ($\sim$ 105).
- One approach is to pick a particular SUSY breaking scenario with few parameters.
- But how well do any or all of these possibilities reflect the true breadth of the MSSM?? Do we really know the MSSM as well as we think??
- Will we be able to discover SUSY at the LHC even if the SUSY breaking mechanism is not what we expected?

- To address these questions, one wants to be as general as possible.
- Due to the size of the MSSM parameter space, some set of assumptions are necessary for practical reasons.
- Different choices of such assumptions could (of course) be made.

Parameters, Ranges, and Scan

- Unfortunately, it is impractical to scan over the above-mentioned 105 parameters (too many!).
- Assume
  - **CP conservation** (removes phases)
  - **Minimal Flavor Violation** (removes off-diagonal terms in mass matrices)
  - **1st and 2nd generation sfermion masses are degenerate** (reduces number of mass parameters)
  - **1st and 2nd generation trilinear couplings negligible** (removes A_e, A_μ, A_u, A_d by setting $= 0$.)
- Hopefully we are still exploring SUSY without **TOO MUCH** prejudice.
- End up with the **pMSSM** (phenomenological MSSM).

Flat Priors 10^7 points

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

Log Priors 2×10^6 points

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

- **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.

No high scale assumptions.

Demanded

- LSP is lightest neutralino and is a thermal relic.
- No tachyons, CCB vacua.
- Higgs potential bounded from below.
- LSP relic density satisfies WMAP limit, 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).
- Contribution to invisible width of the Z less than 2 MeV (LEP).

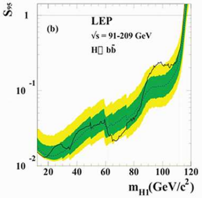
- $\Delta\rho$
- $b \to s\gamma$
- $B \to \mu\mu$
- $g - 2$
- $B \to \tau\nu$

Be in range allowed by experiment.

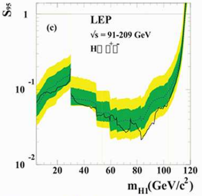
- We also implement Tevatron constraints obtained from limits on trilepton and jet plus missing energy events.
- Use PYTHIA/PGS to simulate ~ 2.1 fb^{-1} of data.
- Use Prospino to calculate K-factors.
- Use SUSY-HIT for the decay table.
- Trilepton constraints: CDF (arXiv:0808.2446 [hep-ex]).
- Jet plus missing energy constraints: D0 (arXiv:0712.3805 [hep- ex]).
- Validate procedure by comparing signal rate obtained using our procedure with than obtained for benchmark models by CDF, D0.
- Models ruled out if non-observance (or $\sim$ 1 event) of process at Tevatron rules out the model at 95% confidence level.

Constraints

Higgs

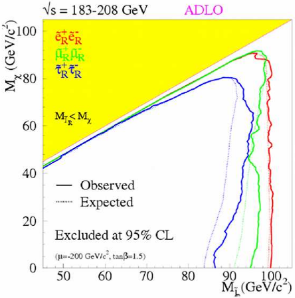


Limits on $(ZZh\ \text{coupling})^2 \times$ BF to $b\bar{b}$ for given Higgs mass (hep-ex/0602042).

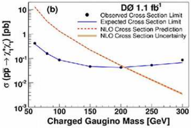


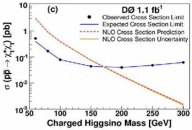
Limits on $(ZZh\ \text{coupling})^2 \times$ BF to $\tau^+\tau^-$ for given Higgs mass (hep-ex/0602042).

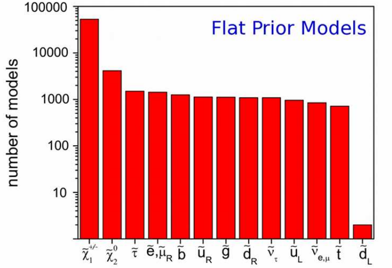
Sleptons



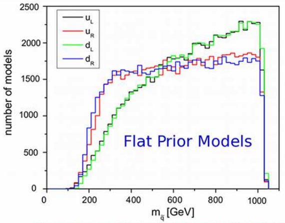
Long-lived Charginos



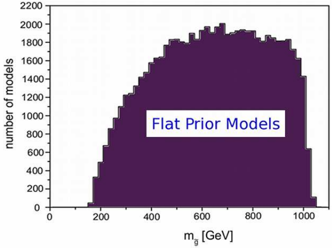




NLSP distribution by sparticle



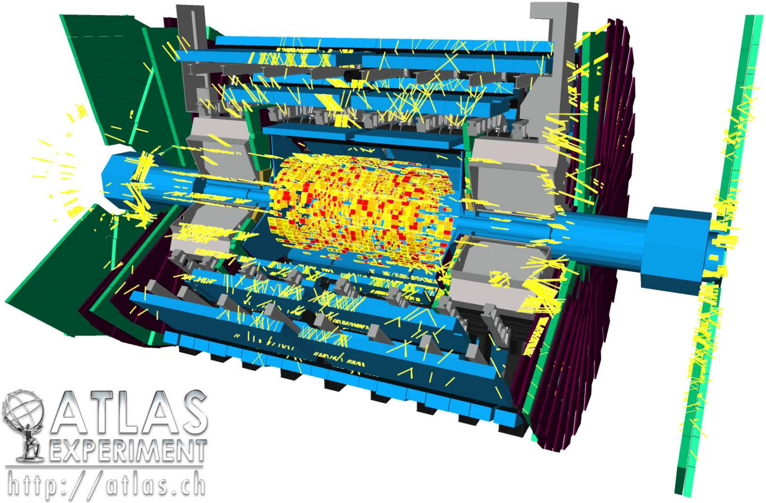
Squark mass distribution: squarks can be light.
PDG bound (degenerate squarks, particular value of μ and $\tan\beta$) is 379 GeV.)



Gluino mass distribution: gluinos can be light!
(PDG bound 308 GeV, assumes gaugino mass unification.)

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

We Have Entered the LHC Era!



Specifically we consider the following analyses, as described in the ATLAS CSC Book (arXiv:0901.0512)).

- Four or more jets, no leptons.
- Three or more jets, no leptons.
- Two or more jets, no leptons.
- Four or more jets, one lepton.
- Three or more jets, one lepton.
- Two or more jets, one lepton.
- Four jets, opposite sign dileptons.
- Four jets, same sign dileptons.
- Trileptons, one jet.
- Trileptons.
- Tau, 4 jets, no leptons.
- Four jets, at least two of which are b-tagged.

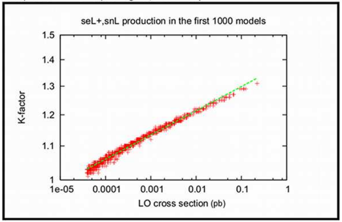
Determine signature for each analysis for all ~70,000 models

Procedure

- Interesting to see if our models are easy/hard to see in these analyses (which have been optimized for mSUGRA points).
- Are there models which are surprisingly easy or hard to see? If so, why?
- What sort of correlations exist between analyses for different models?

*

Calculating K-factors for some processes is very time consuming (which can be a problem when repeating 70, 000 times).



- Hence, (QCD) K-factors for electroweak processes are calculated only for a thousand models.
- Those K-factors are used to find a best fit for K-factor as a function of the LO cross section and obtain the remaining K-factors from that function.

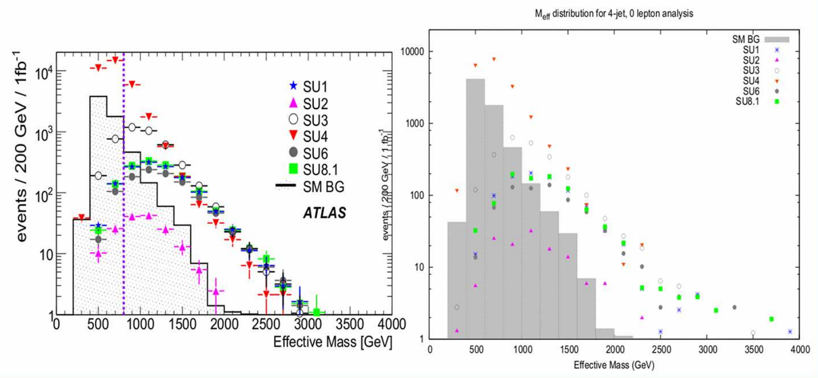
We use ATLAS analyses primarily so that we can use their backgrounds rather than calculating our own.

However, we couldn't generate signal events in exactly the same method as ATLAS.

	ATLAS	Us
Spectrum & decays	ISASUGRA	SUSY-HIT
Event generation, hadronization, and showering	HERWIG	PYTHIA
K-factors	Prospino	Prospino *
Detector simulation	full GEANT	PGS4 LHC tune
Backgrounds	Generated large set of SM processes	Obtained from ATLAS

Verification

- ATLAS used a set of mSUGRA models as benchmarks in the analyses they presented.
- They are labeled SU1, 2, 3, 4, 6, 8.1, and 9.
- To make sure our signal generation was consistent with theirs, we applied our procedure to their benchmarks.
- We agree (I think to a surprising extent).



Significance

Many models have sparticles with mass close to the LSP mass.

We sometimes get PYSTOP errors from PYTHIA- probably due to difficulties in hadronization with so little phase space.

1460 out of 68384 (flat prior) yield PYSTOP errors- these prevent us from simulating that particular process.

The number that have significance $Z_n > 5$ (are visible) for each analysis (at 1 fb^{-1}) is:

Analysis	No. with $Z_n > 5$, no PYSTOPS	No. with $Z_n > 5$, incl. PYSTOPS
4j0l	59537 (88.962 %)	59978 (87.708 %)
2j0l	58719 (87.74 %)	59208 (86.582 %)
1l4j	28560 (42.675 %)	28624 (41.858 %)
1l3j	45228 (67.581 %)	45405 (66.397 %)
1l2j	47011 (70.245 %)	47226 (69.06 %)
OSDL	7360 (10.998 %)	7364 (10.769 %)
SSDL	14280 (21.338 %)	14289 (20.895 %)
3lj	9139 (13.656 %)	9149 (13.379 %)
3lm	1843 (2.7539 %)	1847 (2.7009 %)
tau	57088 (85.303 %)	57483 (84.059 %)
b	49760 (74.353 %)	50113 (73.282 %)

And now, for comparison, we show the same table for 10 fb^{-1}:

Analysis	No. with $Z_n > 5$, no PYSTOPS	No. with $Z_n > 5$, incl. PYSTOPS
4j0l	59682 (89.179 %)	61467 (87.923 %)
2j0l	58806 (87.87 %)	61022 (86.71 %)
1l4j	30565 (45.671 %)	30694 (44.803 %)
1l3j	49636 (74.168 %)	49878 (72.938 %)
1l2j	49854 (74.493 %)	50109 (73.274 %)
OSDL	7957 (11.89 %)	8084 (11.642 %)
SSDL	21487 (32.107 %)	21531 (31.485 %)
3lj	11702 (17.486 %)	11714 (17.13 %)
3lm	1953 (2.9182 %)	1978 (2.8632 %)
tau	58931 (88.057 %)	59440 (86.786 %)
b	51782 (77.374 %)	52342 (76.256 %)

We note a small increase the percentage of models seen in most analyses. For some, there is a significant increase, like the trilepton and SSDL analyses.

Model Visibility

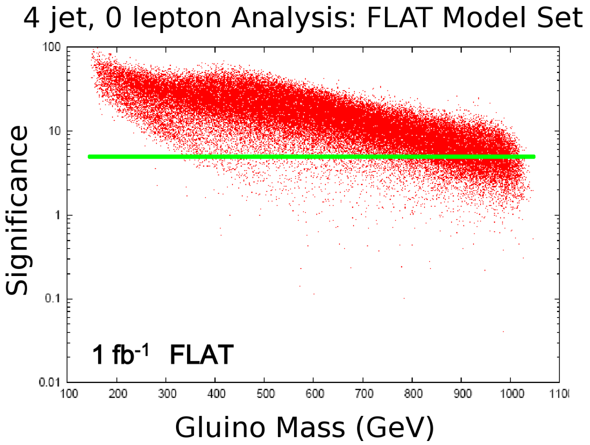
The number of models which were visible ($Z_n > 5$) at $1\,\text{fb}^{-1}$ in exactly n of the analyses is given below.

n	Number with no PYSTOPS	Number incl. PYSTOPS
0	240 (0.35862 %)	1135 (1.6597 %)
1	751 (1.1222 %)	812 (1.1874 %)
2	2110 (3.1528 %)	2168 (3.1703 %)
3	8232 (12.301 %)	8334 (12.187 %)
4	12416 (18.552 %)	12608 (18.437 %)
5	6962 (10.403 %)	7019 (10.264 %)
6	11970 (17.886 %)	12022 (17.58 %)
7	11890 (17.766 %)	11925 (17.438 %)
8	6033 (9.0147 %)	6038 (8.8296 %)
9	2898 (4.3303 %)	2900 (4.2408 %)
10	2654 (3.9657 %)	2655 (3.8825 %)
11	768 (1.1476 %)	768 (1.1231 %)

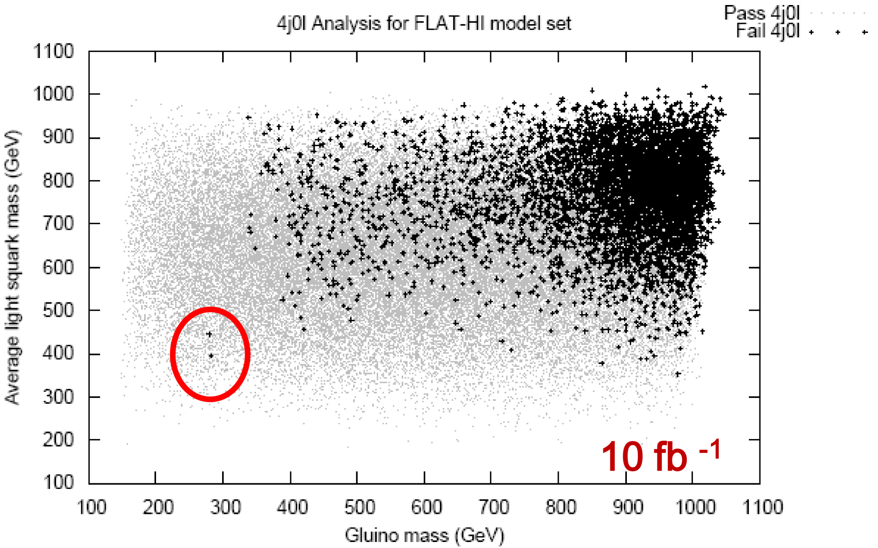
Again, for comparison, we show the same table for $10\,\text{fb}^{-1}$:

n	Number with no PYSTOPS	Number incl. PYSTOPS
0	141 (0.21069 %)	1050 (1.5354 %)
1	477 (0.71275 %)	625 (0.91396 %)
2	1416 (2.1158 %)	1581 (2.3119 %)
3	6571 (9.8186 %)	6803 (9.9482 %)
4	10310 (15.406 %)	10515 (15.376 %)
5	6821 (10.192 %)	6996 (10.23 %)
6	13133 (19.624 %)	13235 (19.354 %)
7	10010 (14.957 %)	10176 (14.881 %)
8	9408 (14.058 %)	9104 (13.313 %)
9	3934 (5.8783 %)	3888 (5.6855 %)
10	3758 (5.6153 %)	3519 (5.1459 %)
11	945 (1.412 %)	892 (1.3044 %)

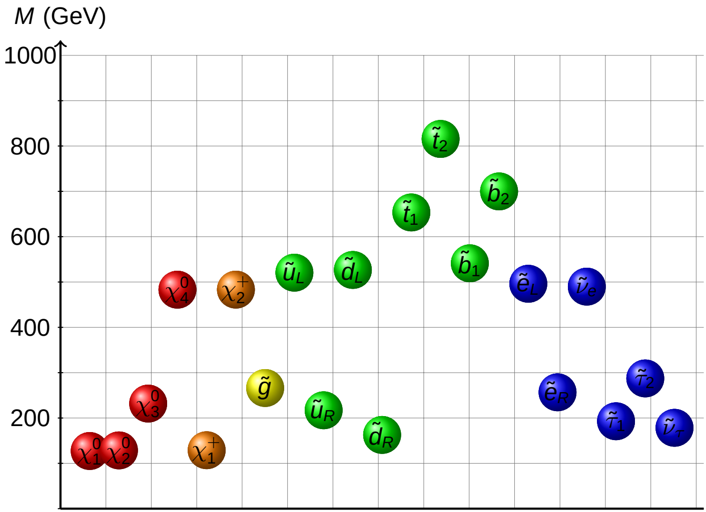
Here we see that while the significance of the signal in the 4 jet analysis decreases as the gluino mass increases, there is still a large spread for any value of the gluino mass,



Models with Light Squarks and Gluinos May Be Missed

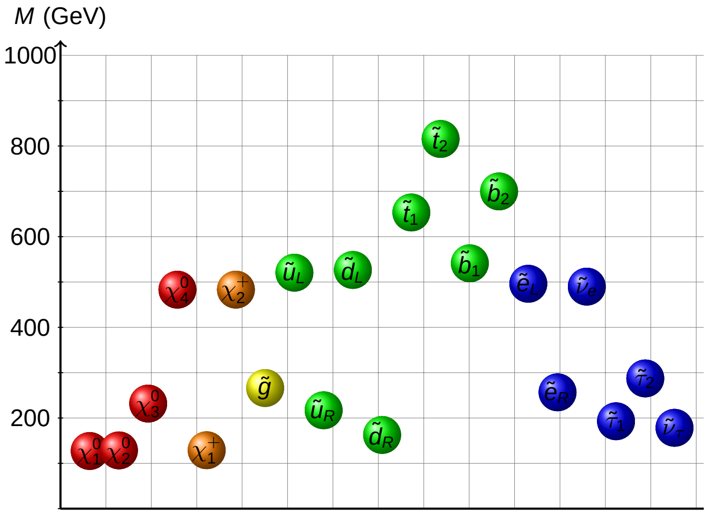


One of the two low gluino mass, low squark mass that fails the 4 jet, 0 lepton analysis has its spectrum shown below.



An Embarrassment of Riches Can Be a Problem!

Small mass separations between the gluino, some squarks and the LSP.
These sparticles' decays produce soft jets, such events do not pass cuts.



- The pMSSM has more phenomenological possibilities than particular SUSY breaking scenarios.
- Studying these models at the LHC may reveal limitations of certain analyses and suggest new analyses to make sure that we learn as much as possible about SUSY at the LHC (if it is realized in Nature and broken at the weak scale).
- Will finish the 14 TeV LHC analysis soon. Would like to examine the 7 TeV case (need analogous ATLAS analysis). Would be interesting to consider other SUSY scenarios, e.g. gravitino LSPs, nMSSM, other SUSY extensions...