BSM SUMMARY, LES HOUCHES WORKSHOP

J. F Gunion, Physics at TeV Colliders, Les Houches, May 30, 2001

- Theory
  - SUSY – Gunion
  - Extra Dimensions – Hewett
- Experiment SUSY and ED — Azuelos

SUSY

- Brief reminder of models and constraints
- The dark matter issue
- The coupling unification issue
- The CMSSM programs and benchmark points
- ‘K’ factors for SUSY Processes
- The Sgoldstino

1 Models and Possible Constraints

- Gravity mediated/universal boundary conditions
  - high scale: m_0, $m_{1/2}$, A_0, $sign(\mu)$, λ_t
  - low scale: evolve the above down to: a) $Q \sim m_{\tilde{t}}$ for effective potential; b) match to low-E at $Q = m_Z$

    RGE Programs

    Programs by different groups differ in various respects.

    * In principle, they should include all higher order corrections, but even those that do differ in exactness of loop corrections included
      (See Table of programs.)
    * $\Rightarrow$ different programs give different results for low-E parameters starting from same GUT boundary conditions. and vice versa.
      (See Tables of point E)
      But, in cases examined, given low-E parameters you can usually find (different) GUT bc that give them for a given program.
    * However, one very sensitive difference emerges: **What is the largest m_0 that you can have as function of $m_{1/2}$ for which RGE EWSB works?**
      $\Rightarrow$ upper limit on sparticle (especially squark and slepton) masses.
      (Show Allanbach graph)

$\Rightarrow$ for now, it appears that large m_0 ($\lesssim$ 10 TeV) still ok with RGE EWSB!

Recall that unification of α_s with other two couplings at M_U prefers sparticle masses significantly above 1 TeV.

– successes: DM can be ok, $g-2$ can be ok, $b \to s\gamma$ can be ok, fine-tuning can be ok.

Dark Matter

Many programs for DM on the market. They don't all include everything they should, and so they don't agree on DM abundance **even given same low-energy inputs.**

(See Dark Matter Program tables)

(Show Dark Matter comparisons for same low-E parameter set)

The most important items that must be treated correctly are:

* All coannihilation channels.
  Especially crucial for region with $m_{\widetilde\chi_1^0} \sim m_{\widetilde\ell_R}$. This gives 'boundary line' extending to very large $m_0, m_{1/2}$ values along which overclosure given high masses is avoided by large co-annihilation rate.
* Widths for all resonances *as a function of parameter point location.* If sit on resonance, $\Rightarrow$ can avoid overclosure at high mass by annihilation through resonance.
  If A^0 and H^0 resonances have narrow width (constant? in KO and some other programs), $\Rightarrow$ narrow 'pipe' to large $m_0, m_{1/2}$.
  (Show KO graph)

If increasingly broad as m_{A^0} increases, $\Rightarrow$ 'hyperbolic section' covering lots of large $m_0, m_{1/1}$ parameter space.
(Show Matchev etal graph, Roszkowski similar)

Important question: Does LEP limit of $m_{h^0} > 113$ GeV require large m_0? Most agree that it does not after all radiative corrections to Higgs mass are in. There is still overlap with the most natural low-mass 'bulb'.

- Anomaly mediated boundary conditions.

  $M_3 : M_2 : M_1 = b_3 : b_2 : b_1$

  $\Rightarrow$ wino LSP and $m_{\widetilde\chi^0_1} \sim m_{\widetilde\chi^\pm_1} \Rightarrow$ very interesting phenomenology:

  - long lifetime for $\widetilde\chi^\pm_1$ possible (show graph)
  - no like-sign dilepton signal
  - heavy $\tilde g$ means limited LHC reach as function of $m_{\widetilde\chi^0_1}$
  - with large m_0, no slepton . . signals

  $m^2_{\widetilde\ell_R} < 0 \Rightarrow$ must introduce additional source: i) universal m_0, ii) U(1) D term contributions; iii) large R-parity violating couplings.

  Generically, flavor changing currents can be small

  Problems:

  - very high $m_{\tilde g} \to$ fine tuning large;
  - $\widetilde\chi^0_1\widetilde\chi^\pm_1$ co-annihilation $\to$ no DM source;
  - relative sign of μ and gaugino masses means hard to fit $g-2$ and $b \to s\gamma$ simultaneously.

– RPV solution to slepton mass

$$(m_E^2)_3 = \frac{m_{3/2}^2}{(16\pi^2)^2}[\lambda_{321}^2(4\lambda_{231}^2 + \lambda_{123}^2 + \lambda_{132}^2) - \frac{198}{25}g_1^4]$$

$\Rightarrow$ **really** large SUSY masses. (Show plot)

Consumers Guide (show it): lots of unhappy faces.

But, the basic idea of loop-induced SUSY breaking is very attractive and very general and emerges in string models as well.

- Gauge mediated supersymmetry breaking

  Recall: $\sqrt{F}$ is the crucial parameter

  SUSY broken in hidden sector with low scale of SUSY breaking $\sqrt{F}$.

  Gravitino mass goes like $F/M_{\rm P}$ while its interactions go like $1/F$.

  – $\sqrt{F}$ can't be too large without gravitinos overclosing universe.

  – If $\sqrt{F}$ is as large as allowed, then LSP decay length of order 1 km or more possible. For smaller $\sqrt{F}$, still significant path length.

    Because of high LHC rates, can pick up km style decay lengths for $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$. Also, good photon pointing allows to detect $c\tau$ as small as b lifetime.

  – If $\sqrt{F}$ is really small ($\lesssim$ 1 TeV), then many interesting new effects.

    Example: Gravitino, goldstino and sgoldstino phenomenology: Sgoldstinos could influence Higgs phenomenology. It's all in COMPHEP. (Show slide by D. Gorbunov)

- Gaugino mediated supersymmetry breaking

  still ok: no discussion here

- Dark Matter boundary conditions.
  - Choose $M_1/M_2 \sim 1 \Rightarrow$ exactly right amount of $\widetilde{\chi}_1^{\pm} - \widetilde{\chi}_1^0$ coannihilation. (show transparencies from Matchev etal)
  - Opens up large $m_0, m_{1/2}$ region dramatically.

- No prejudice boundary conditions

  Let all 105 SUSY parameters be free, and use experiment to find model.

  More realistic: reduce to 16 or so parameters (assuming small CP-phases) (first proposed by JFG and Kelly at snowmass96)

  M_1, M_2, $M_3 = 3$

  $m^2_{\widetilde{t}_L,\widetilde{b}_L}$, $m^2_{\widetilde{t}_R}$, $m^2_{\widetilde{b}_R}$ $\times 3$ for other families $= 9$

  A_t, A_b (ignore 1st two family A's as not important usually) $= 2$

  μ and $B\mu = 2$

  Total $= 16$

  How to sort out? Establish a list of channels (signatures) (JFG+Kelly, SM96):

  - 0ℓ, $\not{E}_T \geq 100$ GeV, $2j$ with $E_T > 100$ GeV, ...
  - repeat same for different cuts and different numbers of jets.
  - 1ℓ, ...
  - $\ell^{\pm}\ell^{\pm}$ like-sign leptons, $\not{E}_T > \ldots, \ldots$

Need hundreds of channels with a (different) set of channels having good rate for a given model.

Must understand channel efficiencies and ‘cross talk’.

CMS scan suggests can establish appropriate channels so that after looking at 4 to 6 of the most relevant channels you single out a rough location in the 16 dimensional parameter space.

Then, start more detailed fitting of distributions etc. to get errors and correlations on the parameters.

- Any model + R-parity violation $\Rightarrow$
  - no dark matter
  - striking leptonic signatures for $\lambda(LLE)$ or $\lambda'(LQD)$
  - possibly difficult signatures for $\lambda''(QQD)$ if combined with AMSB (only jets)
- General DM warning: with appropriate reheating, any particle can be LSP as far as detector is concerned.

  Reheating sufficient to produce strong annihilations would dilute its relic abundance. Thus, don't a priori discard $\tilde{\tau}_R$ as LSP for instance, and higgsino $\widetilde{\chi}_1^0$ would still be ok.

2 Higher Order Corrections

Report by Spira.

New results for $q\overline{q} \to \tilde{g}\widetilde{\chi}$ K factors.

- $q\overline{q} \to \tilde{g}\widetilde{\chi}$ K factor is ~ 1 at Tevatron
- At LHC: $\tilde{g}\widetilde{\chi}$ K factor ranges from $K \sim 1.1$ (high $m_{\tilde{g}}$) to $K \sim 1.17$ (low $m_{\tilde{g}}$).

Don't forget old results for $\widetilde{\chi}\widetilde{\chi}$ and $\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$, the latter having large K factors.

3 Conclusions

Work on these areas will continue, especially getting uniformity in RGE and DM programs.