SUSY, the Third Generation and the LHC

Andrey Katz

C. Brust, AK, S. Lawrence, and R. Sundrum; arXiv:1011.6670

Harvard University

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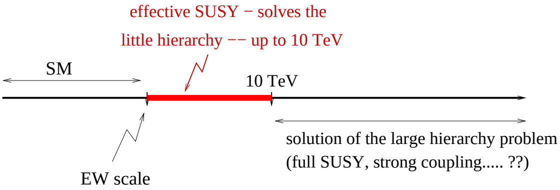
Outline

1. Motivation
2. 10 TeV effective theory – the little hierarchy solution
3. From 10 TeV to 1 TeV – the simplified model
4. Phenomenology of R-parity conserving model
5. R-parity violation

SUSY and the Hierarchy Problem

In this work we take a following approach:



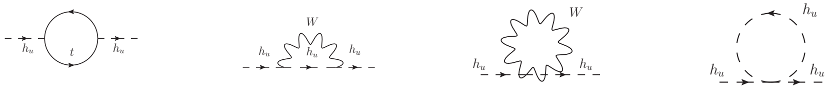
Important: a cutoff of the effective SUSY $\Lambda = 10$ TeV

Little hierarchy approach

From the little hierarchy point of view most of the SUSY scalars are unimportant and we can get rid of them. Important for the little hierarchy: $\tilde{t}, \tilde{W}, \tilde{H}\ldots$

Higgs naturalness

Should address following (most important) divergences:

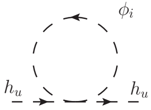


What masses does naturalness ($\Delta m^2 \sim m^2$) demand?

- $m_{\tilde{t}_R, \tilde{Q}_3} \lesssim 400$ GeV – two stops and one sbottom around 400 GeV
- wino, higgsino $\lesssim 1$ TeV
- bino $\lesssim 3$ TeV

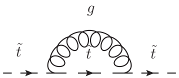
$\tilde{b}_R$ and gluinos

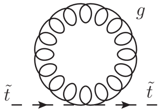
After we introduced new set of scalars, we have one divergent diagram for the higgs. It vanishes only of $Tr\ \ Y = 0$, and to get this we should reintroduce $\tilde{b}_R$. However it is proportional to g'^2 and therefore we expect $m_{\tilde{b}_R} \sim m_{\tilde{B}} \lesssim 3$ TeV



Gluino mass

New light scalars $(\tilde{t}, \tilde{b})$ have there own hierarchy problem:





to cancel these, should introduce gluino, in this mass range get $m_{\tilde{g}} \lesssim 2m_{\tilde{t}}$

New fields at 1 TeV scale

What fields do we expect to detect?

- $\tilde{t}_L$, $\tilde{t}_R$, $\tilde{b}_L$ with masses 400 GeV or less
- $\tilde{g}$ with masses 800 GeV or less – is it allowed by current constraints?
- wino, bino higgsino - maybe , maybe not
- $\tilde{b}_R$ – maybe (in some sense, it's a bino-like particle)

Can we get rid of gluinos?

If gauginos are Majorana, we do not have too much room to play, but gluinos can be Dirac..

Majorana gluinos

$$\Delta m_{\tilde{t}}^2 = \frac{2g_s}{3\pi^2} m_{\tilde{g}}^2 \ln \frac{\Lambda}{m_{\tilde{g}}}$$

the correction is divergent, the log is of order ln 100.

expect $m_{\tilde{g}} \lesssim 2m_t$

Dirac gluinos

$$\Delta m_{\tilde{t}}^2 = \frac{2g_s}{3\pi^2} m_{\tilde{g}}^2 \ln \frac{\delta}{m_{\tilde{g}}}$$

this correction is finite, δ – SUSY breaking mass of the scalar partner in adjoint chiral s-field. The log can easily be e.g. ln 5, and $m_{\tilde{g}} \lesssim 4m_{\tilde{t}}$.

It can be just a difference of factor of 2 or even less in masses, but this difference might be crucial for $\sqrt{s} = 7$ TeV LHC.

On flavor of effective SUSY

Even if the effective IR theory safe, one should worry about the operators at 10 TeV, e.g. $\mathcal{L} \sim \frac{\bar{s}d\bar{s}d}{10\ TeV}$ are still deadly. Such UV completions exist, can have very different logic, but almost identical IR spectrum.

Flavor structure in the IR theory

The choice is not unique, and it cannot be completely anarchical. Assume that the mixings (both in LH and RH sectors) are the same as in Wolfenstein parametrization, namely w/ $\epsilon \approx 0.22$:

- mixing with the first-generation $\sim \epsilon^3$
- mixing with the second generation $\sim \epsilon^2$

Enough to suppress the dangerous terms (but favors a multi-TeV $\tilde{b}_R$).

The most minimal natural model below 1 TeV

- includes $\tilde{t}_L$, $\tilde{t}_R$, $\tilde{b}_L$, all at masses 400 GeV or lower
- assume R-parity for simplicity (not as motivated as in a "regular" SUSY, but still a viable possibility)
- if $\tilde{t}$ or $\tilde{b}$ is the LSP (or more precisely long-living NLSP) – excluded by CMS search for R-hadrons (roughly up to masses 600 GeV)
- there should be a neutralino with the mass below the squarks mass (with or without chargino)

What are constraints on this very minimal scenario? Is it excluded or not?

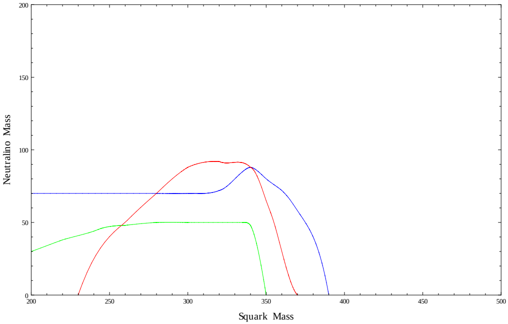
Tevatron searches

- D0 has a dedicated search for $\tilde{b}$ decaying $\tilde{b} \to b\tilde{\chi}^0$, which is just $jets + \not{E}_T$ with b-tag. The most updated bound on the sbottom mass - 245 GeV if the neutralino is massless
- CDF search for $t\bar{t} + \not{E}_T$ (both in monoleptonic and hadronic channels), do not put interesting bounds on a single stop.

Relevant SUSY searches and “accidental” bounds

- jets + $\not{E}_T$ $\Rightarrow$ find bounds from α_T, simple $\not{H}_T$ search
- $l^+ l^- + jets + \not{E}_T$ no bound
- $l + jets + \not{E}_T$ no bound
- $jets + b - tag + \not{E}_T$ no bound (the cuts on H_T, $\not{H}_T$ are too strong, very bad acceptance)
- $b - tag + l + jets + \not{E}_T$ – was designed to catch $\tilde{g} \to \tilde{t} \to \chi$, no bound
- $t\bar{t} + \not{E}_T$ (monoleptonic) – almost no bound on a single top, constrains our model with two tops

Relevant bounds



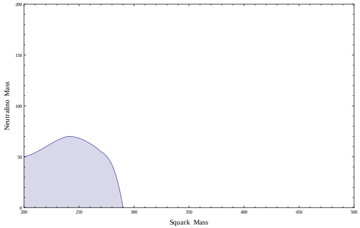
green line - α_T exclusion

red line - monoleptonic $t\bar{t} + \not{E}_T$ exclusion

blue line - simple $\not{H}_T$ search exclusion

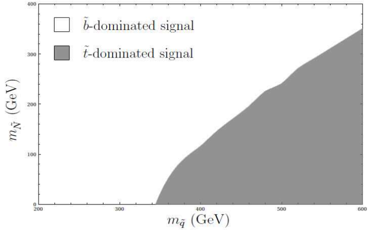
$\tilde{b}$ vs $\tilde{t}$

Where do these bounds come from?



Mostly it is direct $\tilde{b}$ production. Even if we integrate out both $\tilde{t}$, we find a bound on a single $\tilde{b}$. On the other hand there is no analogous bound on $\tilde{t}$.

Where will two stops contribute more than one sbottom?



Why RPV is relevant

Motivations for R-parity:

- proton stability
- DM

Proton stability

Not easy to address in a model with 10 TeV cutoff (with R-parity only). The RP conserving operators

$$W \sim \frac{QQQL}{10\ \ TeV}, \qquad W \sim \frac{u^c u^c d^c e^c}{10\ \ TeV}$$

cause very rapid proton decay.

Dark Matter

Can have a completely non-SUSY origin. Even in SUSY w/ RP need fine-tuning to get correct relic abundance.

In the SM model, there is no proton decay due to accidental symmetries (B and L). It is plausible that one of these symmetries survives also in the effective theory below 10 TeV.

Baryon number violation

In regular SUSY it means $W \sim u^c d^c d^c$, in the effective SUSY with a heavy $\tilde{b}_R$ it is $\mathcal{L} = \tilde{t}^c_R d^c_i d^c_j$.

Constraints

- $K - \bar{K}$ oscillations, constrain the couplings $\mathcal{O}(Y_B)$ (or bigger)
- $n - \bar{n}$ – mild, completely disappear if gauginos are Dirac (in this case even $U(1)_B$ is restored and realized as an R-symmetry.)

Experimental signal:

- $\tilde{t}$ just decays to 2 jets (maybe one of them is b-jet) – extremely challenging signature, interesting what can be the reach of $\sqrt{s} = 7$ TeV LHC in this channel
- $\tilde{b}$ decays either to 2 jets or top and jet – also interesting and challenging channels
- even more interesting if the model is R(B)-symmetric. The LH particles do not mix and decay through gluinos off-shell ($\tilde{t}_L \to tjj$)

BNV with gluinos

Signatures we can consider:

- $t\bar{t} + jets$ probably detectable in cut-and-count measurement of $\sigma(t\bar{t})$. Would be interesting to know what is the bound
- $t\bar{b} + jets$ (if one of the gluinos decays into through $\tilde{t}$, while the second through $\tilde{b}$)
- 6 jets from 2 different resonances, 2 of them b-tagged. This search (w/o b-tag) exists at CMS, was updated only at 35/pb and excludes gluions up to 280 GeV.

Conclusions and Outlook

- analyzed effective SUSY bottom-up, this analysis favors very minimal particle content below 1 TeV scale
- the most interesting bounds one can put on these models come from jets plus $\not{E}_T$ searches, the possibility is far from being excluded
- RPV is extremely motivated, very few searches in this direction have been performed till now, lots of room for new ideas here...