Supersymmetry: Aspirations and Prospects in the LHC Era

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But from a personal perspective

SUSY has been an active area of phenomenological research since the early 1980s.

(Pierre Fayet was way ahead of the curve.)

- Largest possible symmetry of the S-matrix
- Synthesis of bosons and fermions
- Possible connection to gravity (if SUSY is local) and to dark matter (if – motivated by other considerations – we impose R-parity conservation). Richard Arnowitt, Ali Chamseddine and Pran Nath (ACN) pioneered the field of "Applied Supergavity" and brought it into particle physics.

⋆ SUSY solves the big hierarchy problem. Low scale physics does not have quadratic sensitivity to high scales if the low scale theory is embedded into a bigger framework with a high mass scale, Λ.
Only reason for superpartners at the TeV scale.

Bonus: Measured gauge couplings at LEP unify in MSSM but not in SM. Was this real or fortuitous?

Supergravity-based models of particle physics were extremely important. Aside from theoretical niceties to do with gravity, these constructs seemingly automatically solved some practical problems plaguing spontaneously broken globally supersymmetric models; e.g. sum rules that implied a charge $1/3$ squark lighter than the bottom quark!

"Locally Supersymmetric Grand Unification", *PRL 49 (1982) 970*, by ACN was a truly seminal paper.

Supergravity interactions linked SUSY breaking and electroweak symmetry breaking! The model had a gauge singlet field and EWSB occurred at tree level. Today, we have radiative EWSB.

Except for this, and a technical issue about gaugino masses, this paper set up the framework for what became the minimal supergravity (mSUGRA) GUT model that we are so familiar with today.

Over the years, ACN developed this framework and explored many of its observational implications. Led to gainful (?) employment for many of us, and certainly influenced me professionally in many ways. I feel privileged to have had many opportunities to chat about physics with Dick, and learn a little bit of how he thought.

Setting the sparticle mass scale

The physical mass of a spin-zero particle has the form (at one-loop),

$$m_\phi^2 \simeq m_{\phi 0}^2 + C_1 \frac{g^2}{16\pi^2}\Lambda^2 + C_2 \frac{g^2}{16\pi^2} m_{\rm low}^2 \log\left(\frac{\Lambda^2}{m_{\rm low}^2}\right) + C_3 \frac{g^2}{16\pi^2} m_{\rm low}^2 \ . \qquad (1)$$

- ★ Λ^2 term destabilizes the SM if the SM is generically coupled to very high scale physics; $e.g$ GUTs.
- ★ Since Λ^2 terms are absent in softly broken SUSY, the Higgs sector and also vector boson masses are at most logarithmically sensitive to high scale physics.

In SUSY theories, $m_{\rm low} = m_{\rm SUSY}$ and the corrections are $\delta m_h^2 \sim C_2 \frac{g^2}{16\pi^2} m_{\rm SUSY}^2 \times logs \sim m_{\rm SUSY}^2$ (if the logarithm is 30-40). Since LHC says squarks and gluinos are much heavier than m_h^2 or M_Z^2 and so requires fine-tuning.

Setting $\delta m_h^2 < m_h^2 \Rightarrow m_{\rm SUSY}^2 < m_h^2$, and there was much optimism for superpartners at LEP/Tevatron.

$\Delta_{\rm log} = \frac{m_h^2}{\delta m_h^2}$ suggested as a measure of fine tuning.

WHAT WENT WRONG?

- ⋆ Perhaps $\delta m_h^2 < m_h^2$ is too stringent? Many examples of accidental cancellations in nature of one or two orders of magnitude.
- ⋆ Argument applies only to superpartners with large couplings to the EWSB sector (not, $e.g.$ to first generation squarks probed at the LHC).
- ⋆ Most importantly, once we understand the SUSY breaking mechanism, almost certainly we will find that contributions from the various superpartners are correlated, leading to the possibility of automatic cancellations. Ignoring this, will overestimate the UV sensitivity of any model.

Traditionally, the sensitivity is measured by checking the fractional change in M_Z^2 (rather than m_h^2) relative to the corresponding change in the independent parameters (p_i) of the theory. (Ellis, Enqvist, Nanopoulos, Zwirner, reinvented and explored by Barbieri and Giudice): $\Delta_{\rm BG} = Max_i \frac{p_i}{M_Z^2}\frac{\partial M_Z^2}{\partial p_i}$

$$\Delta_{\log} \geq \Delta_{\rm BG},$$

since $\Delta_{\log}$ ignores correlations we just mentioned.

Electroweak Fine-Tuning (Baer talk)

$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2,$$

(Σ_u^u, Σ_d^d are finite radiative corrections.)

Requiring no large cancellations on the RHS, motivates us to define, $\Delta_{\rm EW} = max\left(\frac{m_{H_u}^2}{\frac{1}{2}M_Z^2}\frac{\tan^2\beta}{\tan^2\beta-1}, \frac{\Sigma_u^u}{\frac{1}{2}M_Z^2}\frac{tan^2\beta}{\tan^2\beta-1}, \cdots\right)$. Small $\Delta_{\rm EW} \Rightarrow m_{H_u}^2,\ \mu^2$ close to M_Z^2 as emphasized by Chan, Chattopadhyay and Nath in 1998.

$\Delta_{\rm EW} \leq \Delta_{\rm BG}$ (modulo some technical caveats) because it has no logs in it. For this reason, Mustafayev and I regard it as a bound on the fine-tuning in a high scale theory rather than a fine-tuning measure. Put differently, $\Delta_{\rm EW}$ is the minimum fine-tuning in any theory with a given spectrum, while $\Delta_{\rm BG}$ is always the true fine-tuning measure in a high scale theory. (arXiv:1404.1386)

If sparticle masses (in some theory) are suitably correlated so the $\log\frac{\Lambda^2}{m_{\rm SUSY}^2}$ terms essentially cancel, $\Delta_{\rm BG} \to \Delta_{\rm EW}$.

The utility of $\Delta_{\rm EW}$

- ⋆ $\Delta_{\rm EW}$ is essentially determined by the SUSY spectrum.
- ⋆ If $\Delta_{\rm EW}$ is large, the underlying theory that leads to the spectrum will be fine-tuned. A small $\Delta_{\rm EW}$ does not imply the theory is not fine-tuned, but leaves open the possibility of finding such a meta-theory of SUSY breaking parameters.

  If within a model with small $\Delta_{\rm EW}$, $\Delta_{\rm BG} \simeq \Delta_{\rm EW}$, then this framework is not fine-tuned and the masses have required correlations. Essential to evaluate both $\Delta_{\rm BG}$ and $\Delta_{\rm EW}$ before declaring victory on fine-tuning (arXiv:1404.1386).
- ⋆ Many aspects of the phenomenology depend just on the spectrum, so this can be investigated even without knowledge of the underlying high scale theory.[a]
- ⋆ Low $\Delta_{\rm EW} \Longrightarrow$ low $|\mu|$, but squarks (including stops) may be much heavier.

We think low $|\mu|$ more basic to fine-tuning considerations than light stops. This feature is hidden by many analyses of fine-tuning.

Quite generally, light higgsinos are a necessary feature of models with low fine-tuning.

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[a] Beware though of pheno implications that depend on strong correlations (other than those dictated by fine-tuning considerations) in the spectrum.

Loopholes in the light higgsino argument

- ⋆ Assumes the superpotential μ parameter is independent of soft SUSY breaking parameters.

- ⋆ Assumes the higgsino mass indeed comes mostly from $|\mu|$; i.e. no explicit SUSY breaking higgsino mass (This would be a hard SUSY breaking in the presence of singlets that couple to the Higgsinos). Indeed, Nelson and Roy (arXiv:1501.03251) and S. Martin (Pheno 2015 talk) have constructed models with additional adjoint chiral superfields where the Higgs and higgsino mass parameters are independent.

- ⋆ The Higgs could be a (pseudo) Goldstone boson in a theory with global symmetry even if $|\mu|$ is large. Cancellations that give low Higgs mass (and concomitantly low M_Z^2) are then a result of a symmetry. (Cohen, Kearney and Luty, PRD 91 (2015) 075004). Origin of global symmetry???

Despite these caveats, we will regard low μ as a necessary condition for naturalness, and explore its observational implications. The argument is good for simplest models.

Realizing Small $\Delta_{\rm EW}$ (and small $|\mu|$)

Baer has already introduced the the Radiatively-driven Natural SUSY (RNS) framework which leads to small $\Delta_{\rm EW}$ within the NUHM2 model.

Since it is an independent parameter, we can always tune $m_{H_u}^2(\Lambda)$ to get small $m_{H_u}^2(\rm weak)$ as required.

This is not an empty statement. Small $\Delta_{\rm EW}$ cannot be realized in mSUGRA, and also in many other constrained models (Baer, Barger, Mickelson, Padeffke-Kirkland). A large value of $\Delta_{\rm EW}$ signals that there <u>must</u> be fine-tuning in the theory.

Finally, to get small $\Delta_{\rm EW}$, we also have to ensure that the finite radiative corrections from SUSY particle loops, Σ_u^u, are small. This requires large, negative $A_0 \sim -1.6 m_0$. This large $|A_0|$ simultaneously raises m_h to its observed value.

We are not saying that the NUHM2 model point with small $\Delta_{\rm EW}$ has low fine-tuning. Indeed, the fact that A_0 and $m_{H_u}^2$ have to be adjusted to get low $\Delta_{\rm EW}$ says otherwise.

However, if we had a theory of soft-parameters that predicted $A_0 = -1.6m_0$ and $m_{H_u}^2 = 1.64m_0^2$ (these correlations yield low $\Delta_{\rm EW}$) this meta-theory would be a candidate for a theory that is not fine-tuned. In such a theory, $\Delta_{\rm BG}$ would automatically become numerically close to $\Delta_{\rm EW}$ because the large logs would automatically cancel once the fact that the parameters are correlated is incorporated. We do not have such a theory today!!!!

Since this theory has the same spectrum as the RNS scenario, it will have the same phenomenological implications because the phenomenology is mostly determined by the spectrum. The NUHM2 model is a surrogate for exploring the phenomenology of this (as yet unknown) theory with low fine-tuning.

Motivation and interpretation for $\Delta_{\rm EW}$ somewhat different from that of Baer and collaborators (arXiv:1309.2984, 1404.2277), but these differences are unimportant for practical purposes, and do not affect the importance of $\Delta_{\rm EW}$.

RNS Spectrum characteristics

- ⋆ Four light higgsino-like inos, $\widetilde{Z}_{1,2}$, $\widetilde{W}_1^{\pm}$;
- ⋆ $m_{\tilde{t}_1} = 1-2$ TeV; $m_{\tilde{t}_2} = 2-4$ TeV;
- ⋆ $m_{\tilde{g}} = 1-5$ TeV (else $\tilde{t}$s becomes too heavy and make Σ_u^u too large); (Resulting bino and wino mass parameters consistent with low $\Delta_{\rm EW}$ is we assume unification.)
- ⋆ Split the generations and choose $m_0(1,2)$ large to ameliorate flavour and CP issues (This is separate from getting small $\Delta_{\rm EW}$).

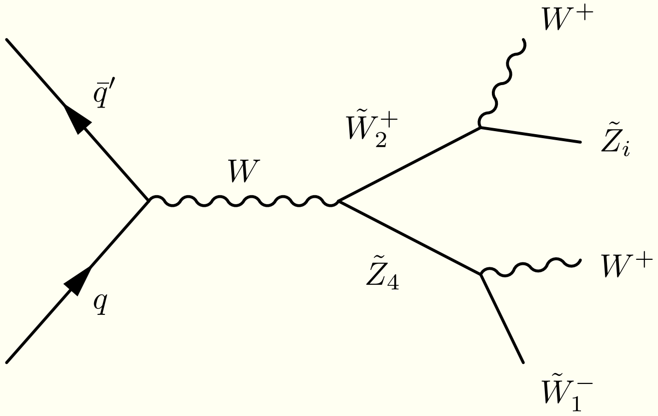
Large intra-generation splittings among heavy first/second generation squarks leads to large $\Delta_{\rm EW}$ except for specific mass patterns. (PRD 89, 037701 (2014))

Broad Brush RNS Phenomenology at the LHC

- ★ Light higgsino-like states $\widetilde{W}_1^{\pm}$, $\widetilde{Z}_2$, $\widetilde{Z}_1$ must be present with masses $\sim |\mu| \ll |M_{1,2}|$, and generically small splittings.
- ★ If $|M_{1,2}|$ also happens to be comparable to $|\mu|$, these states would be easy to access at the LHC via $\widetilde{W}_1\widetilde{Z}_2$ production, or at a *LC via $\widetilde{W}_1\widetilde{W}_1$, $\widetilde{Z}_1\widetilde{Z}_2$ and $\widetilde{Z}_2\widetilde{Z}_2$ production. Heavier -inos may also be accessible.
- ★ In the generic case, the small mass gap may makes it difficult to see the signals from electroweak higgsino pair production at the LHC because decay products are very soft (even though the cross section is in the pb range for 150 GeV higgsinos).
- ★ Monojet/monophoton recoiling against higgsinos also does not work. Can reduce backgrounds by requiring additional soft leptons from higgsino decays.
- ★ Gluino pair production, if it is accessible at the LHC, will lead to signals rich in b-jets because we have assumed first/second generation squarks are very heavy. However, gluinos may not be accessible.

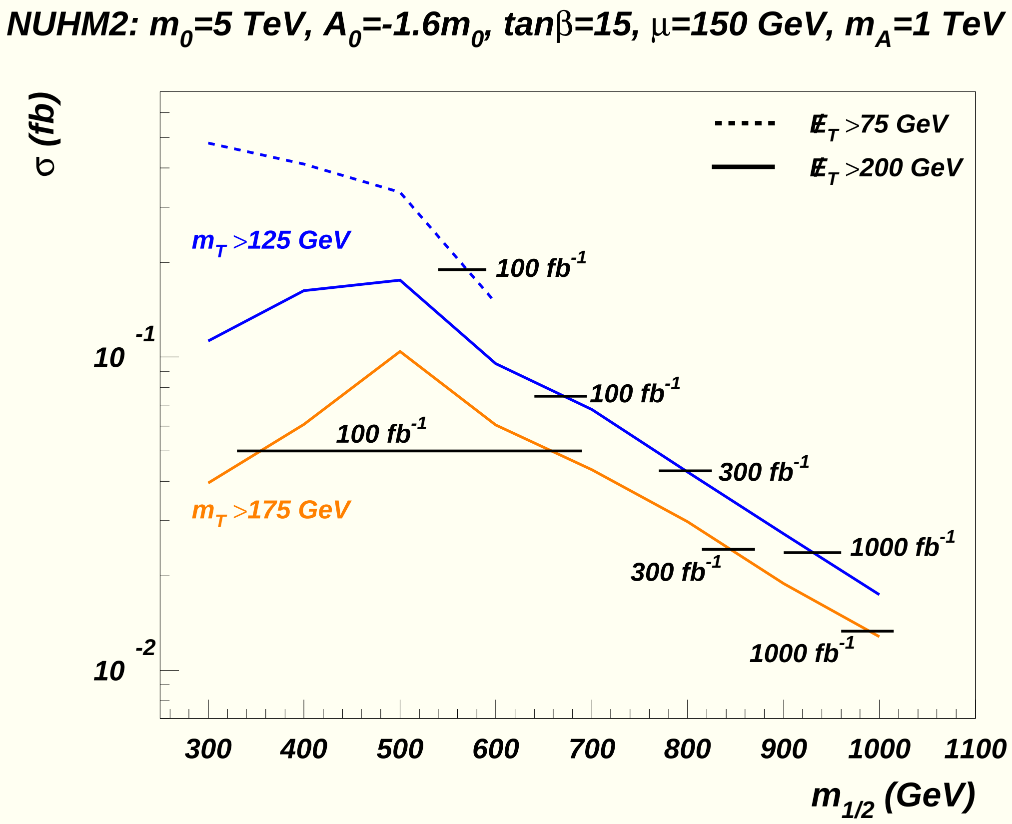
Light higgsinos at the LHC

- ⋆ A novel signal is possible at the LHC if $|M_2| \lesssim 0.8 - 1$ TeV, something that is possible, though not compulsory, for low $\Delta_{\rm EW}$ models.



Decays of the parent $\widetilde{W}_2$ and $\widetilde{Z}_4$ that lead to W boson pairs with the same sign 50% of the time. Novel same sign dilepton events with hard jet activity only from QCD radiation. (Remember that the decay products of higgsino-like $\widetilde{W}_1$ and $\widetilde{Z}_2$ are typically expected to be soft.)

This new signal may point to the presence of light higgsinos.



Hard cuts on $\not{E}_T$ and minimum transverse mass $m_T(\ell_{1,2}, \not{E}_T)$ is crucial to pull out the signal.

Jet-free Multilepton Signals

In addition to the novel SS dilepton signal without jets, heavy wino production can also lead to observable rates for other interesting signatures.

- ⋆ Clean trilepton events from $pp \to \widetilde{W}_2\widetilde{W}_2, \widetilde{W}_2\widetilde{Z}_4X \to WZ + \not{E}_T$ events. (the so-called golden signature for EW-ino production pointed out by ACN, and others).
- ⋆ Four lepton signatures that arise because a lepton from the cascade decay of a heavy wino to a light higgsino is also identified (confirmatory channel indicating low μ).
- ⋆ These signals are in addition to usual jetty signals from gluino production (if gluino production is accessible) where cascade decays would, e.g. lead to OS, SF dilepton events with characteristic dilepton mass edge at $m_{\ell\ell} \leq m_{\widetilde{Z}_2} - m_{\widetilde{Z}_1}$.

A Recap of the LHC14 Reach for RNS in terms of $m_{\tilde{g}}$/TeV

Int. lum. (fb^{-1})	$\tilde{g}\tilde{g}$	SSdB	$WZ \to 3\ell$	4ℓ
10	1.4	–	–	–
100	1.6	1.6	–	~ 1.2
300	1.7	2.1	1.4	$\gtrsim 1.4$
1000	1.9	2.4	1.6	$\gtrsim 1.6$

The canonical gluino signature yields the highest reach only for integrated luminosities up to 100 fb^{-1}. For higher integrated luminosities, the SSdB channel yields the best reach. The SSdB signal is a generic characteristic of small $|\mu|$ models.

If the SSdB signal is present, there may be confirmatory signals in the 3ℓ and 4ℓ channels.

However, these signals and also signals from t-squarks may all be inaccessible at LHC13

Monojet Signals

There has been much talk about detecting natural SUSY via inclusive $\not{E}_T$ + monojet events from $pp \to \widetilde{W}_1\widetilde{W}_1, \widetilde{W}_1\widetilde{Z}_{1,2}, \widetilde{Z}_{1,2}\widetilde{Z}_{1,2} + jet$ production, where the jet comes from QCD radiation.

- ⋆ Many analyses done using effective 4-fermion operators. This approximation is invalid because higgsino production dominantly occurs via s-channel Z exchange.
- ⋆ Although there is an observable rate, even after hard cuts, the signal to background ratio is typically at the percent level. We are pessimistic that the backgrounds can be controlled/measured at the subpercent level needed to extract the signal in the inclusive $\not{E}_T$ + monojet channel. (Baer, Mustafayev, XT arXiv:1401.1162; C. Han *et al.*, arXiv:1310.4274; P. Schwaller and J. Zurita, arXiv:1312.7350)

★ However, as first noted by G. Giudice, T. Han, K. Wang and L-T. Wang, and elaborated on by Z. Han, G. Kribs, A. Martin and A. Menon that backgrounds may be controllable by identifying soft leptons in events triggered by a hard monojet.

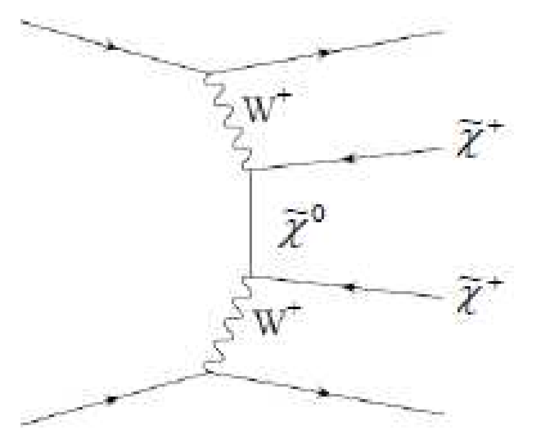
OS/SF dilepton pair with $m_{\ell\ell} < m_{\ell\ell}^{\rm cut}$ analysis with $m_{\ell\ell}^{\rm cut}$ as an analysis variable.

Alternatively, examine dilepton flavour asymmetry $\frac{N(SF)-N(OF)}{N(SF)+N(OF)}$ in monojet plus OS dilepton events.

LHC14 reach extends to about $|\mu| = 170$ (200) GeV for integrated luminosity of 300 (1000) fb^{-1}. See A. Mustafayev talk for details.

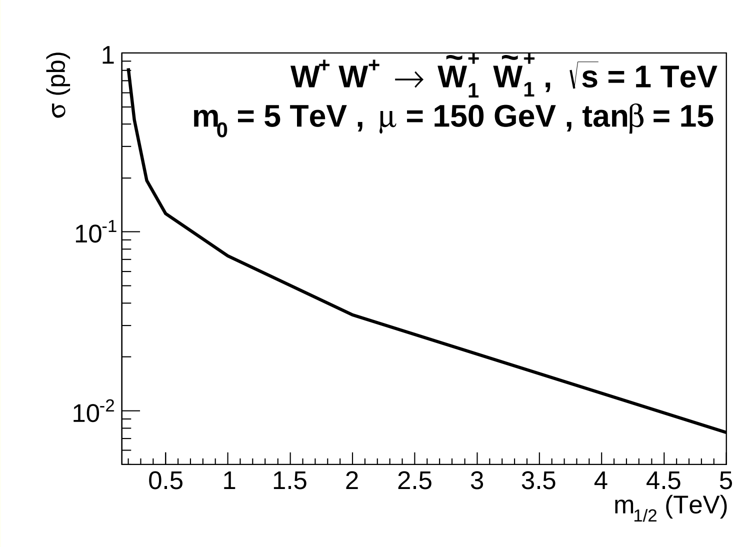
Nice that it probes the best motivated μ range, but not a decisive probe of $\Delta_{\rm EW} < 30$ (3% fine-tuning).

Motivated by the fact that ATLAS has been able to probe $W^+W^+ \to W^+W^+$ scattering, we considered same sign charged higgsino pair production $pp \to \widetilde{W}_1^\pm \widetilde{W}_1^\pm jjX$ in natural SUSY that occurs via t-channel exchange of neutralinos. Cho et al. PRD 73 (2006) 054002; Giudice, Han, Wang^2 PRD 81 (2010) 115001 Also, many VBF studies by the Texas A and M group.



To our surprise, we found that the cross section for $pp \to \widetilde{W}_1^\pm \widetilde{W}_1^\pm jjX$ production falls off very fast with increasing $m_{1/2}$ even though the chargino mass is not changed.

To understand what was going on, we examined $W^\pm W^\pm \to \widetilde{W}_1^\pm \widetilde{W}_1^\pm$.



As $m_{1/2}$ increases, $\widetilde{W}_1$ and $\widetilde{Z}_2$ become increasingly higgsino-like, and the cross section drops off rapidly although $m_{\widetilde{W}_1}$ hardly changes across the figure!

Realized that in the $M_{1,2} \to \infty$ limit, the two degenerate neutral higgsinos can be written as one Dirac higgsino ($\widetilde{Z}_D$) and then, the $W\overline{\widetilde{W}_1}\widetilde{Z}_D$ coupling has an extra conserved $U(1)$ charge where $\widetilde{W}_1^+$ and $\widetilde{W}_1^-$ have equal and opposite charges, as do $\widetilde{Z}_D$ and $\overline{\widetilde{Z}_D}$ (gaugino number). An exact U(1) symmetry if sfermions decouple.

The SS chargino production is suppressed because it does not conserve gaugino number.

With hindsight, we can also see suppression of the cross-section by examining the MSSM amplitudes; the contribution from $\widetilde{Z}_1$ and $\widetilde{Z}_2$ exchanges cancel exactly in the limit that the winos and binos are very heavy.

The bottom line

Same sign higgsino production is likely not a viable channel at LHC14 if gauginos and squarks are very heavy as expected in natural SUSY. (With P. Stengel)

Non-universal Gaugino Masses

Up to now, we have assumed unification of gaugino mass parameters. Then the LHC bound on the gluino forces the EW gauginos to be heavy.

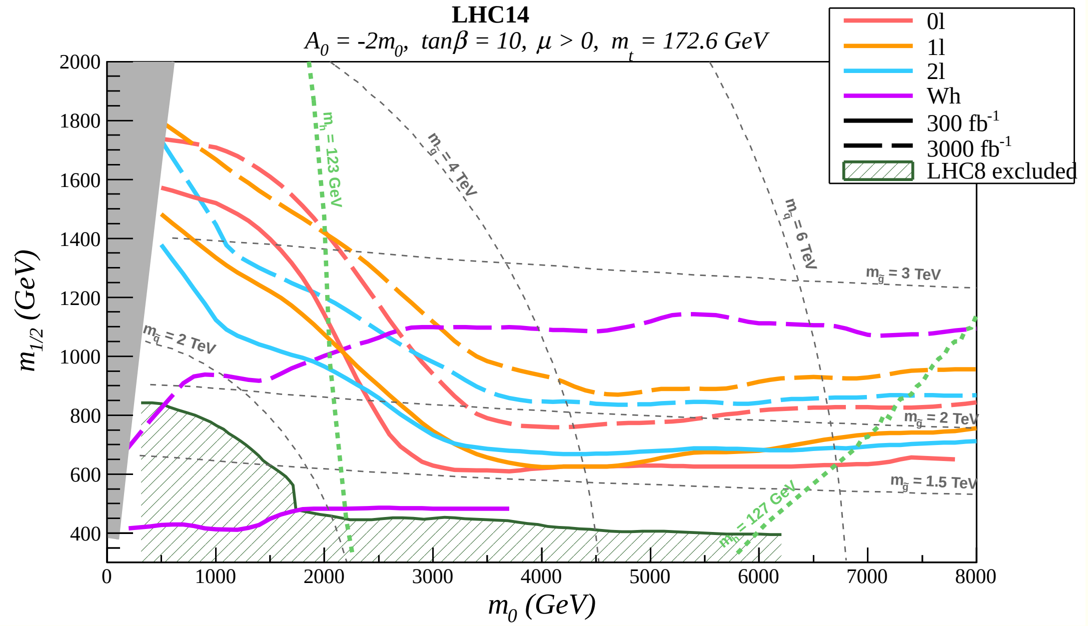
It is, however, possible that $M_{1,2}$ are independent of $M_3 \simeq m_{\tilde{g}}$, and one or the other (or both) is fortituously small. This does not have an impact on $\Delta_{\rm EW}$ but does impact collider and DM phenomenology.

In particular, if the bino and/or wino is accessible at LHC (and $|\mu|$ is also small as necessary for naturalness) signals from $\widetilde{Z}_3$, $\widetilde{Z}_4$ and $\widetilde{W}_2$ could occur at observable rates, as the mass gap between these states and the higgsinos is typically large.

Multilepton events, $WZ+ \not{E}_T$ events and $Wh+ \not{E}_T$ events generic in such scenarios. (LHC collaborations are searching for these!)

DM may all be a well-tempered thermal neutralino if the bino is light, but would have to have other components (axions, perhaps) if $|M_2|$ happens to be small.

High Luminosity LHC: mSUGRA



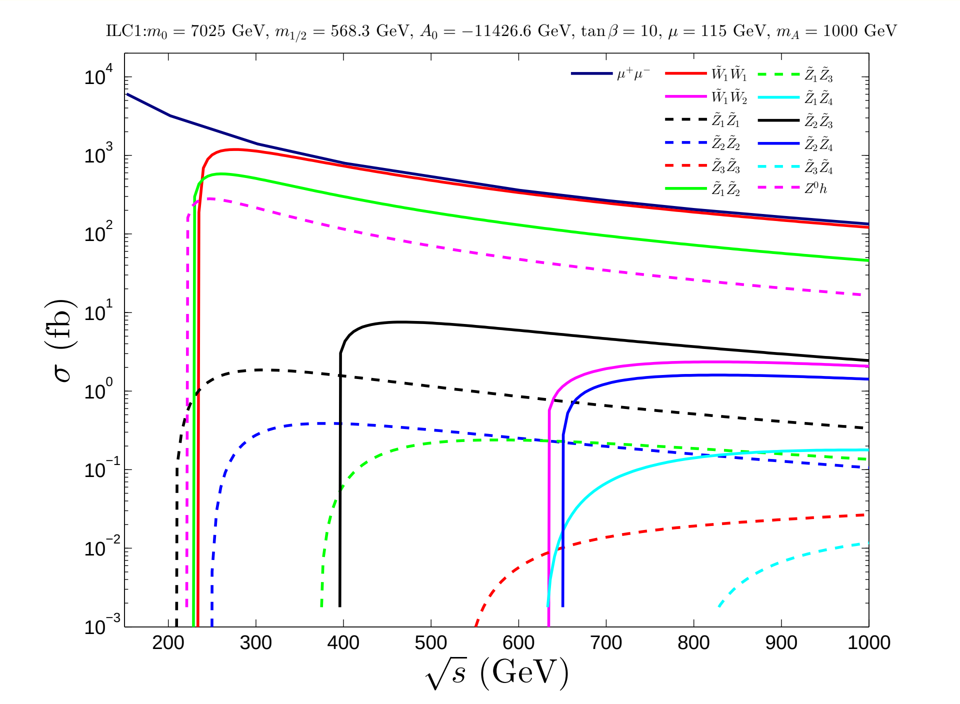
Baer,Barger,Lessa,XT

Notice that at very high integrated luminosity, and very high m_0 the reach in $m_{1/2}$ is dominated by the $Wh+\not{E}_T$ channel.

This is because gluino and squark production is kinematically suppressed and $\widetilde{W}_1\widetilde{W}_1$ and $\widetilde{W}_1\widetilde{Z}_2$ production are the dominant production mechanisms. Since $B(\widetilde{Z}_2 \to \widetilde{Z}_1 h)$ and $B(\widetilde{W}_1 \to W\widetilde{Z}_1)$ are essentially 100%, this channel dominates at very high integrated luminosity.

We have seen that natural SUSY may remain undetectable at LHC13 because gluinos squarks, binos and winos are too heavy, and higgsino production events are too soft because $\widetilde{W}_1 - \widetilde{Z}_1$ and $\widetilde{Z}_2 - \widetilde{Z}_1$ mass gaps are 10-30 GeV in RNS.

Fortunately, the ILC is a higgsino factory!



The cross section for higgsino production exceeds that for Higgs boson production if the higgsinos and Higgs bosons have similar production thresholds.

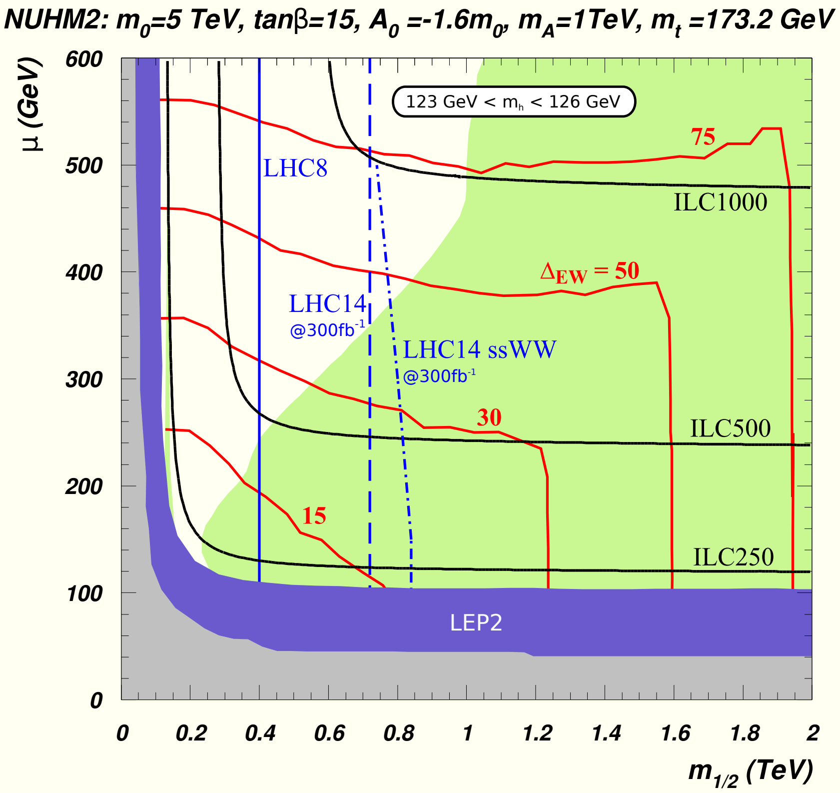
Even for the small mass gaps, signals from $e^+e^- \to \widetilde{W}_1\widetilde{W}_1$ and$\widetilde{Z}_2\widetilde{Z}_1$ production should be readily detectable at an electron-positron collider if these reactions are kinematically accessible and we have electron beam longitudinal polarization.

Moreover, the clean environment makes precision measurements of masses possible.

Along with cross section measurements, the mass measurements would point to higgsinos as the underlying new physics, and possibly also suggest a link to a natural origin of gauge and Higgs boson masses.

No time for details here, but please see talk by A. Mustafayev and also JHEP 1406 (2014) 072.

An overview of the collider reach in RNS



The green region is where the thermal relic density of neutralinos is smaller than 0.12.

There is a large region of parameter space with $\Delta_{\rm EW} < 30$ not accessible at LHC14, but kinematically accessible at a 600 GeV e^+e^- collider which would be a machine that would probe naturalness at the 3% level.

FINAL REMARKS

- Obituaries of SUSY seem premature. The LHC has run at 60% of its design energy and accumulated $< 10\%$ of the anticipated integrated luminosity.
- Our original aspirations remain unchanged if we accept that "accidental cancellations" at the few percent level are ubiquitous, and DM may be multi-component. SUSY GUTs pioneered by ACN remain as promising as ever. Eagerly awaiting LHC13.
- Viable natural spectra with light higgsinos exist without a need for particles beyond MSSM.
- Light higgsinos seem necessary for the most economic versions of naturalness, and may yield novel LHC signals.
- Light higgsino scenarios cannot saturate the total CDM; nonetheless, assuming gaugino mass unification, there is enough thermal higgsino DM fraction that will reveal itself in direct and indirect DM searches. (Baer, Barger, Mickelson)
- An e^+e^- collider with $\sqrt{s} \gtrsim 600$ GeV could be a discovery machine for light higgsinos for $\Delta_{\rm EW} \lesssim 30$; $i.e.$ no worse than 3% fine-tuning.

Back up slides

Illustrate how correlations make $\Delta_{\rm BG} \to \Delta_{\rm EW}$

In a previous study, we had found that the NUHM2 model point $(\textbf{Case A})$

$$(m_0, m_{1/2}, A_0, \tan\beta, \mu, m_A) = (2500, 400, -4000, 10, 150, 1000)$$

(mass parameters in GeV), gives $\Delta_{\rm EW} = 11.3$, with $\Delta_{\rm BG} = 3168$.

If these values come from a theory that automatically correlated parameters such that $A_0 = 1.6 m_0$ and $m_{H_u}^2 = 1.64 m_0^2$, $\Delta_{\rm BG} \to 257$!

If, in addition, $m_{1/2}$ is also correlated with m_0 so that $m_{1/2} = 0.4 m_0$, $\Delta_{\rm BG} \to 15.4$.

We repeated this for a second point $(\textbf{Case B})$ with

$$(m_0, m_{1/2}, A_0, \tan\beta, \mu, m_A) = (4000, 1000, -4000, 15, 150, 2000)$$

(mass parameters in GeV) and $\Delta_{\rm EW} = 17$ and $\Delta_{\rm BG} = 8553$.

If these values come from a theory that automatically correlated parameters such that $A_0 = 1.6 m_0$ and $m_{H_u}^2 = 1.70 m_0^2$, $\Delta_{\rm BG} \to 1123$!

If, in addition, $m_{1/2}$ is also correlated with m_0 so that $m_{1/2} = 0.25 m_0$, $\Delta_{\rm BG} \to 55$.

This table shows what I just told you on the last slide.

Correlation	**Case A**	**Case B**
None	3168	8553
$A_0 = \xi_A m_0,\ m_{H_u}^2 = \xi_H m_0^2$	257	1123
$m_{1/2} = \xi_{1/2} m_0$	15.4	55
$\Delta_{\rm EW}$	11.3	17

A. Mustafayev and XT, arXiv:1404.1386

Parameter correlations reduce $\Delta_{\rm BG}$ and bring it close to $\Delta_{\rm EW}$.

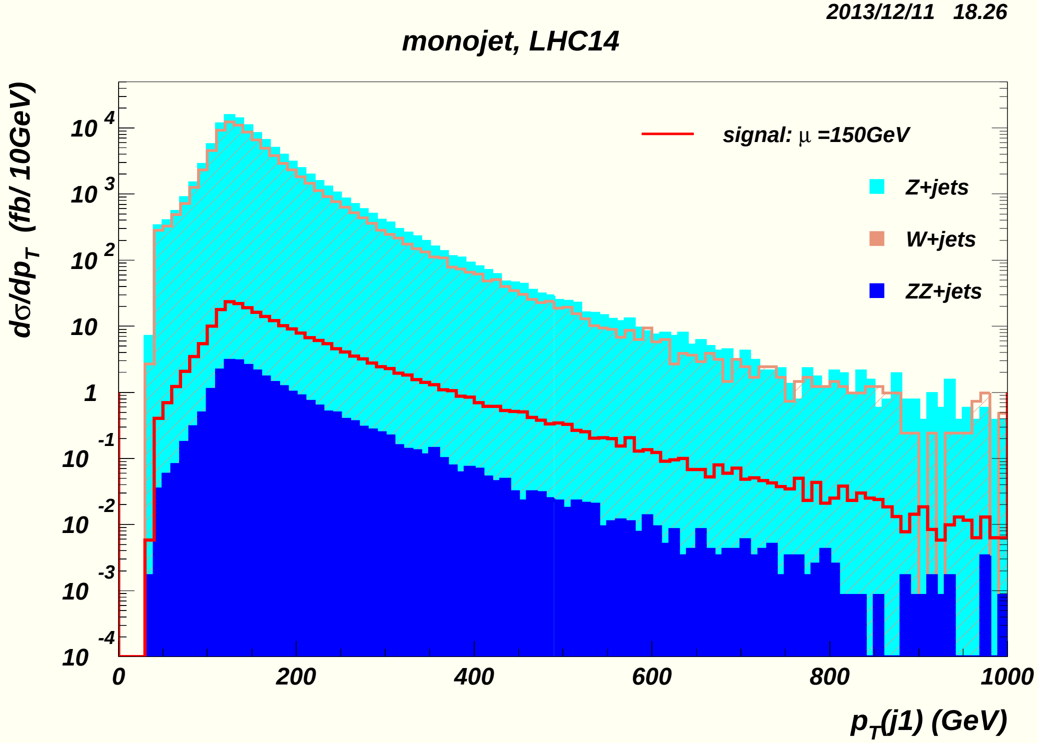
CORRELATIONS AMONG HIGH SCALE PARAMETERS CAN LEAD TO AUTOMATIC CANCELLATIONS AMONG THE LOGS, AND THE UNDERLYING META-THEORY WILL NOT BE FINE-TUNED.

WE STRESS THAT JUST THE META-THEORY IS NOT FINE-TUNED, AS SHOWN BY THE VALUE OF THE TRUE FINE-TUNING MEASURE $\Delta_{\rm BG}$.

The low value of $\Delta_{\rm EW}$ in the effective theory offers the possibility that the spectrum of this theory will, one day, be derived from such a meta-theory.

I wish I could tell you how this will happen.

The correlations reduce $\Delta_{\rm BG}$ by two orders of magnitude because of automatic cancellations. This means that the calculation of $\Delta_{\rm BG}$ has to be done with a percent level precision; *e.g.* cannot just use the approximate formulae for one-loop RGE running. We can discuss the technicalities associated with doing so off-line.



Similar result for $\not{E}_T$ distribution.

Similar results for mono-photons.