Supersymmetry: Aspirations and Prospects

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But from a personal perspective

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

- 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).

⋆ 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

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 SUSY breaking, 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

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

(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.

Since $\Delta_{\rm EW}$ has no large logs in it, $\Delta_{\rm EW} \leq \Delta_{\rm BG}$ (modulo some technical caveats). For this same reason,

<u>it cannot be interpreted as a measure of fine-tuning in a high scale theory.</u> But nonetheless it is very useful, as we will see.

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 large logs are hidden because in I wrote $m_{H_u}^2 = m_{H_u}^2(\Lambda) + \delta m_{H_u}^2$.)

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.
- ⋆ Many aspects of the phenomenology depend just on the spectrum, so this can be investigated even without knowledge of the underlying high scale theory.

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

Loopholes to 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 (reasonable, as this would be hard SUSY breaking in the presence of singlets that couple to the Higgs sector).
- ⋆ 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). Origin of global symmetry???

Despite these caveats, I will regard low μ as a necessary condition fo naturalness, and explore its observational implications.

Realizing Small $\Delta_{\rm EW}$

In the weak scale EWSB condition, in order not to have large cancellations, we clearly need to have $m_{H_u}^2(\text{weak})$ (and also μ^2) close to M_Z^2. This is not guaranteed in mSUGRA, but always possible in the NUHM2 model, since $m_{H_u}^2$ is an adjustable parameter. Tune $m_{H_u}^2(\Lambda)$ to get small $m_{H_u}^2(\text{weak})$.

$$\text{NUHM2 parameters}: m_0, m_{1/2}, A_0, \tan\beta\ + m_{H_u}^2, m_{H_d}^2$$

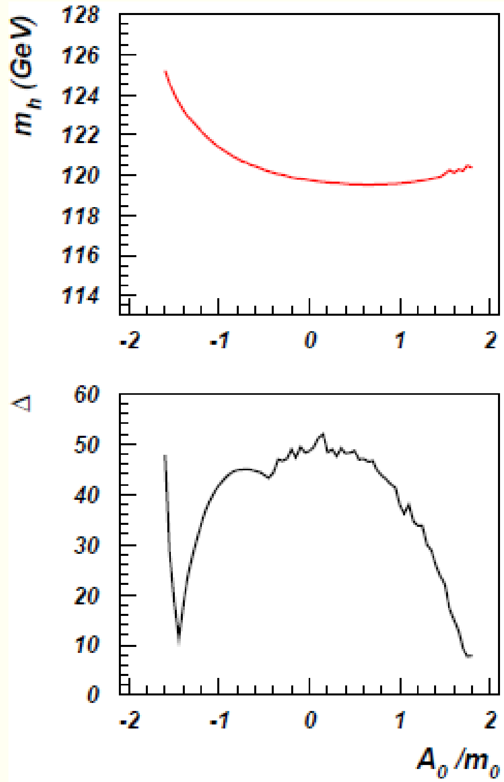
This is not an empty statement. Small $\Delta_{\rm EW}$ cannot be realized in mSUGRA, and also in many other constrained models (Baer, Barger, Mickelson, Padeffke-Kirkland). A large value of $\Delta_{\rm EW}$ signals there must be fine-tuning in the theory.

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.

Contributions dominantly come from top squark loops.

The $\tilde{t}_2$ contribution is $\propto \ln \frac{m_{\tilde{t}_2}}{m_{\tilde{t}_1}} - 1$, and so often small.

The $\tilde{t}_1$ constribution suppressed for large A_t values realized for large, negative A_0.



Thus, $\Delta_{\rm EW}$ falls sharply for $A_0 \sim -1.6m_0$.

This same A_0 raises the Higgs mass!

Remember, $\Delta_{\rm EW}$ is a bound on the fine-tuning, so we are not saying that the NUHM2 model point has low fine-tuning. Indeed, the fact that A_0 and $m^2_{H_u}$ 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 $m^2_{H_u} = 1.64m_0^2$ the values that give low $\Delta_{\rm EW}$, this meta-theory would be a candidate for a theory that is not fine-tuned. We do not have such a theory today!!!!

In such a theory, the high scale fine-tuning measures 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.

In any case, $\Delta_{\rm EW}$ is always the minimum fine-tuning in any theory with a given spectrum, and $\Delta_{\rm BG}$ is always the true fine-tuning measure of a high scale theory. (arXiv:1404.1386)

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 relevance of $\Delta_{\rm EW}$.

Radiatively-driven Natural SUSY

These considerations led us to the radiatively-driven natural SUSY framework for generating spectra with low $\Delta_{\rm EW}$ that may be useful for phenomenological analyses.

In the NUHM2 model, perform a scan over;

- $m_0 = 1 - 7$ TeV; $A_0 = -(1-2)m_0$; $\tan\beta = 5 - 50$;
- $\mu = 100 - 300$; m_A= your choice

Find points with $\Delta_{\rm EW} < 30$, consistent with phenomenological constraints.

We then examine the phenomenology of these low $\Delta_{\rm EW}$ RNS scenarios that are obtained from the NUHM2 model.

Underlying philosophy is that if we find an underlying theory of SUSY breaking parameters with low $\Delta_{\rm BG}$ that yields essentially the same spectrum, it will have the same phenomenological implications since these are 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.

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 $\Delta_{\rm EW}$.)
- ⋆ 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.

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.

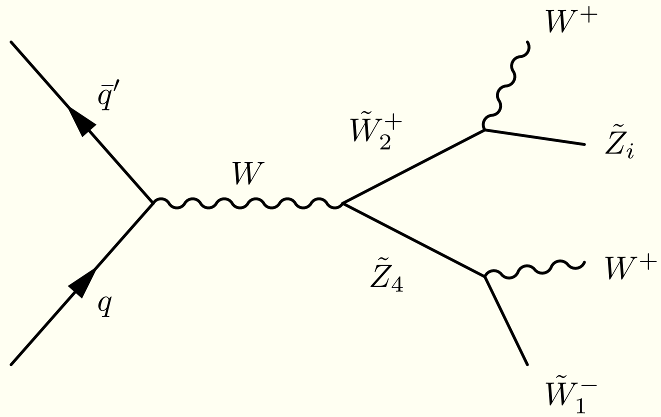
- ★ In the generic case, the small mass gap may makes it difficult to see the signals from electroweak higgsino pair production at the LHC because decay products are very soft (even though the cross section is in the pb range for 150 GeV higgsinos).

- ★ 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.

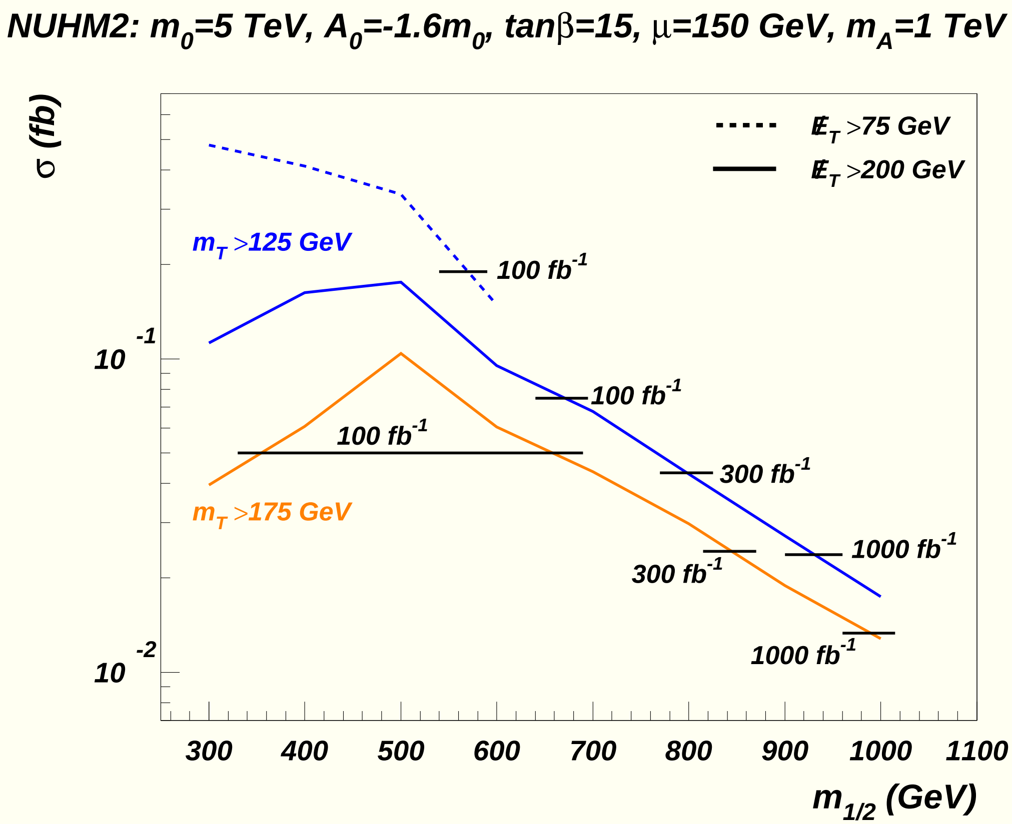
Light higgsinos at the LHC

★ 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 give the same sign 50% of the time. Novel same sign dilepton events with jet activity essentially only from QCD radiation since 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. (Deja vu: we first studied trilepton signals with Kaoru nearly 30 years ago!)
- ★ 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 $m_{\ell\ell} \le m_{\widetilde{Z}_2} - m_{\widetilde{Z}_1}$.

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 LHC14

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.

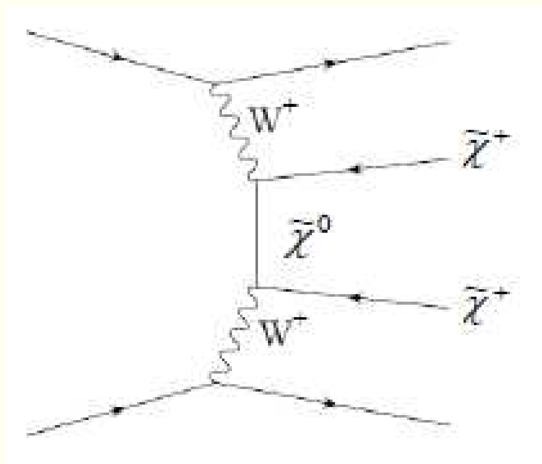
OS/SF dilepton pair with $m_{\ell\ell} < m_{\ell\ell}^{\rm cut}$ analysis with $m_{\ell\ell}^{\rm cut}$ as an analysis variable.

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}. Baer, Mustafayev and XT

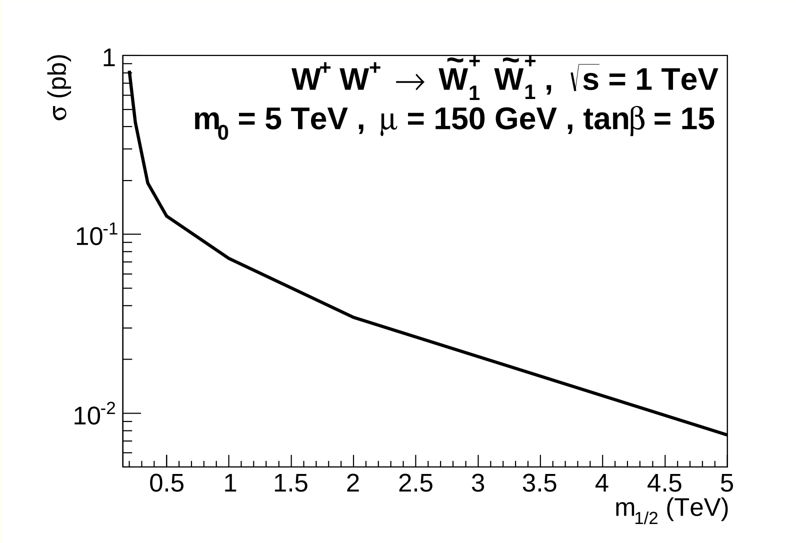
Nice that it probes the best motivated μ range, but not a decisive probe of $\Delta_{\rm EW} < 30$.

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. 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 of very fast with increasing $m_{1/2}$ even if 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). Exact 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 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 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 had assumed unification of gaugino masses. Then the LHC bound on the gluino forces the EW gauginos to be heavy.

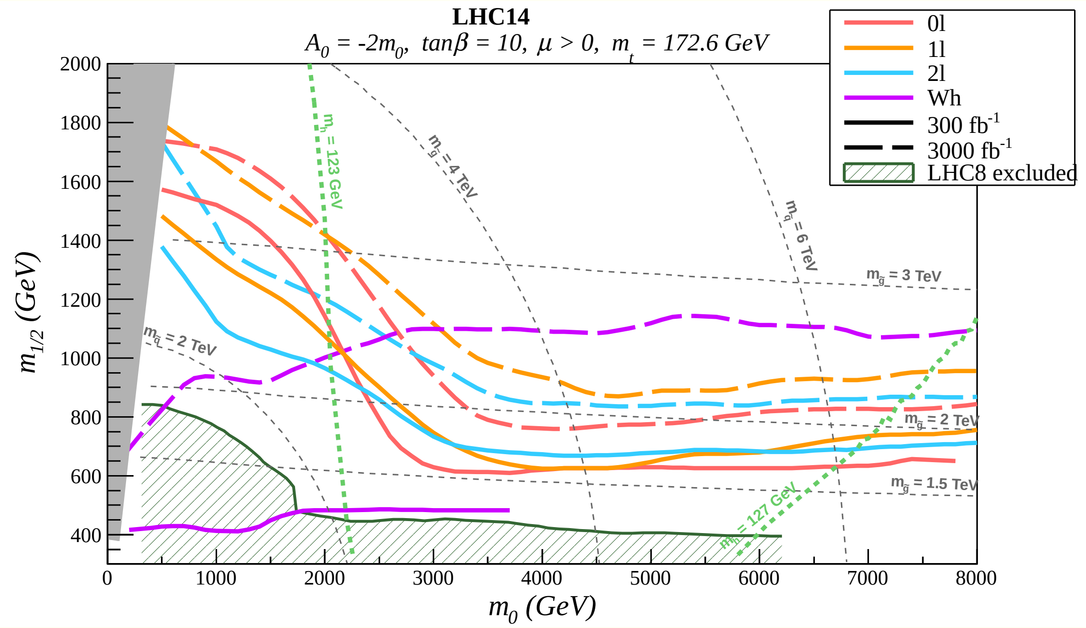
It is, however, possible that $M_{1,2}$ are independent of $M_3 \simeq m_{\tilde{g}}$, and one or the other (or both) is fortituously small. This does not have an impact on $\Delta_{\rm EW}$ but does impact collider and DM phenomenology.

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

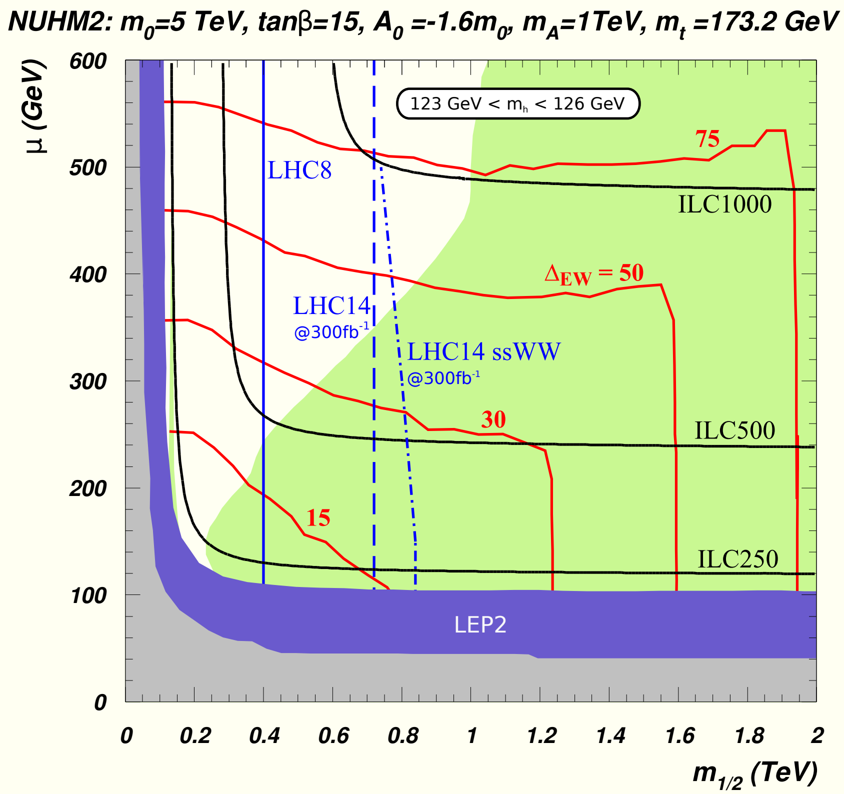


Baer,Barger,Lessa,XT

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.

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, and perhaps also suggest a link between the new physics and the origin of W, Z and h masses . (See Baer's talk)

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 remain a KAERU. Eagerly awaiting LHC13.
- ⋆ Viable natural spectra exist without a need for superpartners beyond MSSM.
- ⋆ Light higgsinos seem necessary for naturalness and <u>may</u> yield novel LHC signals.
- ⋆ $\Delta_{\rm EW}$ is "directly" measurable (in principle) so we can tell that a given spectrum is fine-tuned if $\Delta_{\rm EW}$ turns out to be large.
- ⋆ 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

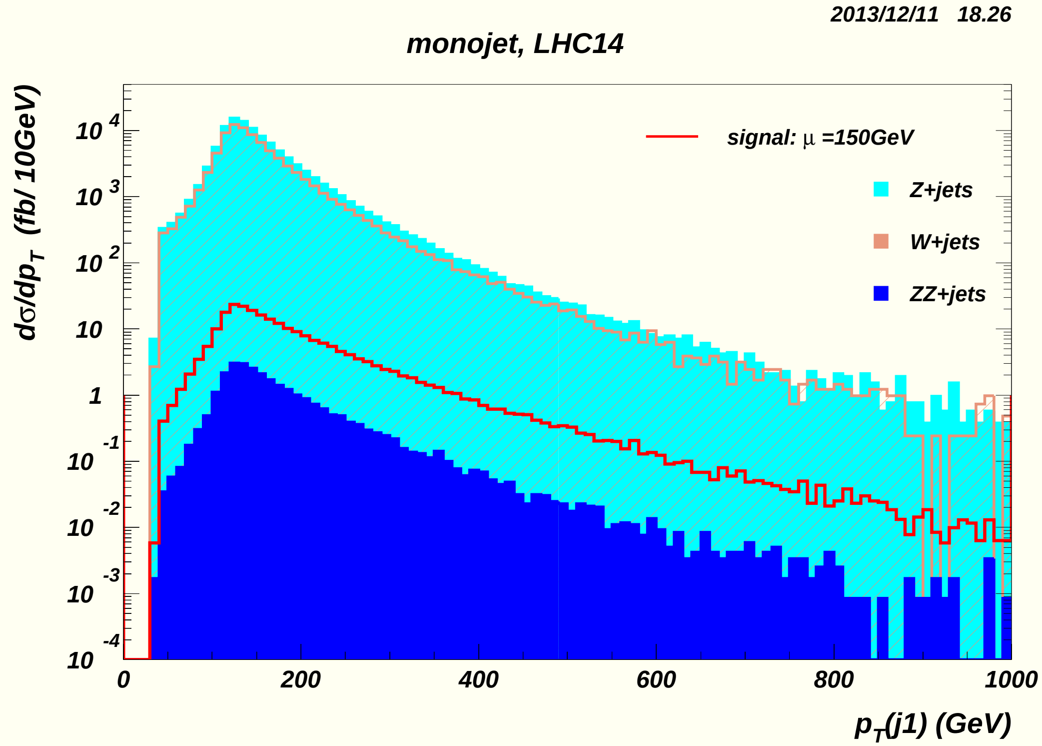
Parameter correlations reduce $\Delta_{\rm BG}$ and bring it close to $\Delta_{\rm EW}$.

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.