

SUPERSYMMETRY AFTER LHC RUN I

Mariana Frank

Concordia University

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LHC RESULTS

LHC results at center-of mass $\sqrt{s} = 8$ TeV and $\mathcal{L} = 20 \text{ fb}^{-1}$, if available;
If not, results at $\sqrt{s} = 7$ TeV and $\mathcal{L} = 5 \text{ fb}^{-1}$

- LHC confirms SM by the discovery of the Higgs boson;
- And puts in jeopardy any BSM predicting new particles with mass close to the EW scale. [Not just SUSY, any model which explains the naturalness of the weak scale]
- Run I is complete: but intriguing hints could still appear in data not yet released/analyzed.
- Even if nothing is found, still hope for LHC @13 TeV or 14 TeV.
- And are we looking in the right region/searching for right signals?

WHAT WE KNOW SO FAR OF SUSY

ADVANTAGES OF SUSY

- It resolves the hierarchy problem without UV sensitivity;
- Predicts that EW symmetry broken by elementary scalar particle;
- It predicts the Higgs mass to lie below 135 GeV;
- It provides a dark matter candidate;
- Decoupling properties excellent, agreement with precision limits on EW observables.

DISADVANTAGES OF SUSY: WHERE IS EVERYBODY?



WHAT DID WE EXPECT: I. NATURALNESS

- 1 Introduce a symmetry to control radiative corrections to elementary scalar masses to Planck scale. [SUSY, no quadratic dependence]
 - high scales for logarithmic dependence on the cutoff; and
 - quadratic dependence on lighter particle masses.
- 2 Introduce a cutoff of the effective theory containing the elementary scalar. [extra-dimensional theories]

IMPORTANT PARAMETERS

- Soft mass, Higgs coupling from tree level $M_Z^2 = -2(m_{H_u}^2 + \mu^2) \dots$
 $\implies \mu \lesssim 200 \text{ GeV}.$
- Stop masses from loop corrections $\delta m_{H_u}^2 = -\frac{3Y_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right),$
 $\implies m_{\tilde{t}} \lesssim 400 \text{ GeV}, \Lambda \sim 10 \text{ TeV}.$
- Wino masses from loop corrections $\delta m_{H_u}^2 = -\frac{3g^2}{8\pi^2} (m_{\tilde{W}}^2 + m_h^2) \ln\left(\frac{\Lambda}{m_{\tilde{W}}}\right),$
 $\implies m_{\tilde{W}} \lesssim \text{TeV}.$
- Gluino masses $\delta m_{\tilde{t}}^2 = \frac{2g_s^2}{3\pi^2} m_{\tilde{g}}^2 \ln\left(\frac{\Lambda}{m_{\tilde{g}}}\right), \implies m_{\tilde{g}} \lesssim 2m_{\tilde{t}}.$

WHAT DID WE EXPECT II: MSSM

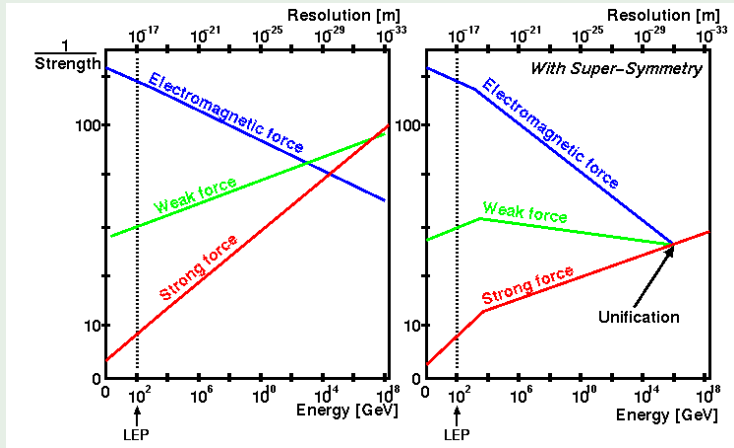
STANDARD MODEL

- $\begin{pmatrix} u \\ d \end{pmatrix}_L, \begin{pmatrix} \nu \\ e \end{pmatrix}_L, u_R, d_R, e_R$
quarks, leptons
- W^\pm, Z, γ, g
W, Z bosons, photon, gluon
- $\begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix}, \begin{pmatrix} H_2^0 \\ H_2^- \end{pmatrix}$
Higgs bosons

MSSM: MINIMAL EXTENSION

- $\begin{pmatrix} \tilde{u} \\ \tilde{d} \end{pmatrix}_L, \begin{pmatrix} \tilde{\nu} \\ \tilde{e} \end{pmatrix}_L, \tilde{u}_R, \tilde{d}_R, \tilde{e}_R$
squarks, sleptons
- $\tilde{W}^\pm, \tilde{Z}, \tilde{\gamma}, \tilde{g}$
Wino, Zino, photino, gluino
- $\begin{pmatrix} \tilde{H}_1^+ \\ \tilde{H}_1^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_2^0 \\ \tilde{H}_2^- \end{pmatrix}$ Higgsino
- $(\tilde{W}^\pm, \tilde{H}_{1,2}^\pm) \Rightarrow (\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm)$
 $(\tilde{Z}^\pm, \tilde{\gamma}, \tilde{H}_1^0, \tilde{H}_2^0) \Rightarrow \tilde{\chi}_{1,2,3,4}^0$

- minimal fields for $N = 1$ anomaly-free SUSY;
- SUSY breaking scale high;
- number of fundamental breaking parameters small;
- colored particles heavier than uncolored ones.



- Baryon and lepton number violating operators allowed \implies impose R -parity, lightest R -odd particle is the LSP.
- MSSM provides a natural DM candidate with mass \sim GeV.
- Expect SUSY decay chains with pairs of LSP, i.e., significant \cancel{E}_T .

SUMMARY OF SEARCHES FOR SUSY-ATLAS

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

ATLAS Preliminary

$$\int \mathcal{L} dt = (4.6 \cdot 22.9) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$$

Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_{\text{miss}}^{\text{min}}$	$[\mathcal{L} dt(\text{fb}^{-1})]$	Mass limit	Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{\chi}_1^0 \rightarrow m(\tilde{\chi}_1^0)$
	MSUGRA/CMSSM	1, ϵ, μ	3-6 jets	Yes	20.3	any $m(\tilde{\chi}_1^0)$
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	any $m(\tilde{\chi}_1^0)$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow \tilde{q}\tilde{q}^\dagger$	0	2-6 jets	Yes	20.3	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow \tilde{q}\tilde{q}^\dagger$	0	2-6 jets	Yes	20.3	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow \tilde{q}\tilde{q}^\dagger \rightarrow \tilde{q}\tilde{q}W^{*H^\pm}$	1, ϵ, μ	3-6 jets	Yes	20.3	$m(\tilde{\chi}_1^0) = 200 \text{ GeV}, m(\tilde{\tau}^{\pm}) = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{g}))$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow \text{negligible } \tilde{q}\tilde{q}^\dagger \rightarrow \tilde{q}\tilde{q}W^{*H^\pm}$	2, ϵ, μ	0-3 jets	-	20.3	$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$
	GMSB (\tilde{L} NLSP)	2, ϵ, μ	2-4 jets	Yes	4.7	$m(\tilde{\chi}_1^0) > 1.24 \text{ TeV}$
	GMSB (\tilde{L} NLSP)	1-2, τ	0-2 jets	Yes	20.7	$m(\tilde{\chi}_1^0) > 1.4 \text{ TeV}$
	GGM (bino NLSP)	2, γ	-	Yes	20.3	$m(\tilde{\chi}_1^0) > 50 \text{ GeV}$
	GGM (bino NLSP)	1, $\epsilon, \mu, \tau, \gamma$	-	Yes	4.8	$m(\tilde{\chi}_1^0) > 50 \text{ GeV}$
	GGM (higgsino-bino NLSP)	1, $\epsilon, \mu, \tau, \gamma$	1 b	Yes	4.8	$m(\tilde{\chi}_1^0) > 520 \text{ GeV}$
GGM (higgsino NLSP)	2, ϵ, μ (Z)	0-3 jets	Yes	5.8	$m(\tilde{\chi}_1^0) > 200 \text{ GeV}$	
Gravitino LSP	0	mono-jet	Yes	10.5	$m(\tilde{\chi}_1^0) > 10^{-4} \text{ eV}$	
$\tilde{\chi}_1^0$ ann. & $\tilde{\chi}_1^0$ prod.	$\tilde{\chi}_1^0 \rightarrow b\bar{b}$	0	3 b	Yes	20.1	$m(\tilde{\chi}_1^0) = 800 \text{ GeV}$
	$\tilde{\chi}_1^0 \rightarrow t\bar{t}$	0	7-10 jets	Yes	20.3	$m(\tilde{\chi}_1^0) > 350 \text{ GeV}$
	$\tilde{\chi}_1^0 \rightarrow \tau\bar{\tau}$	0-1, ϵ, μ	3 b	Yes	20.1	$m(\tilde{\chi}_1^0) > 400 \text{ GeV}$
	$\tilde{\chi}_1^0 \rightarrow b\bar{b}\tilde{\chi}_1^0$	0-1, ϵ, μ	3 b	Yes	20.1	$m(\tilde{\chi}_1^0) > 300 \text{ GeV}$
$\tilde{\chi}_1^0$ ann. squarks & direct production	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$m(\tilde{\chi}_1^0) > 100-620 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	2, ϵ, μ (SS)	0-3 b	Yes	20.7	$m(\tilde{\chi}_1^0) \geq m(\tilde{\chi}_1^0)$
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	1, 2, ϵ, μ	1-2 b	Yes	4.7	$m(\tilde{\chi}_1^0) > 55 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1 \rightarrow W\tilde{t}_1^\dagger$	2, ϵ, μ	0-2 jets	Yes	20.3	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W)$
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	2, ϵ, μ	2 jets	Yes	20.3	$m(\tilde{\chi}_1^0) > 1 \text{ TeV}$
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$m(\tilde{\chi}_1^0) > 200 \text{ GeV}, m(\tilde{\tau}^{\pm}) > 5 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	1, ϵ, μ	1 b	Yes	20.7	$m(\tilde{\chi}_1^0) > 0 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$m(\tilde{\chi}_1^0) > 200-610 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1 \rightarrow \tilde{t}_1\tilde{t}_1$	0	mono-jet+tag	Yes	20.3	$m(\tilde{\chi}_1^0) > 90-200 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2, ϵ, μ (Z)	1 b	Yes	20.3	$m(\tilde{\chi}_1^0) > 150-580 \text{ GeV}$
	$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3, ϵ, μ (Z)	1 b	Yes	20.3	$m(\tilde{\chi}_1^0) > 200 \text{ GeV}$
	EW direct	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$	2, ϵ, μ	0	Yes	20.3
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}\tilde{\chi}_1^0$		2, ϵ, μ	0	Yes	20.3	$m(\tilde{\chi}_1^0) > 140-465 \text{ GeV}$
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		2, τ	-	Yes	20.7	$m(\tilde{\chi}_1^0) > 180-330 \text{ GeV}$
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		3, ϵ, μ	0	Yes	20.3	$m(\tilde{\chi}_1^0) > 180-330 \text{ GeV}$
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		2, τ	-	Yes	20.3	$m(\tilde{\chi}_1^0) > 700 \text{ GeV}$
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^\dagger$		2-3, ϵ, μ	0	Yes	20.3	$m(\tilde{\chi}_1^0) > 420 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow W\tilde{t}_1^\dagger$		1, ϵ, μ	2 b	Yes	20.3	$m(\tilde{\chi}_1^0) > 285 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow W\tilde{t}_1^\dagger$		1, ϵ, μ	2 b	Yes	20.3	$m(\tilde{\chi}_1^0) > 285 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		2, ϵ, μ	-	Yes	20.3	$m(\tilde{\chi}_1^0) > 90-325 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		2, ϵ, μ	0	Yes	20.3	$m(\tilde{\chi}_1^0) > 140-465 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow \tau\bar{\tau}\tilde{\chi}_1^0$		2, τ	-	Yes	20.7	$m(\tilde{\chi}_1^0) > 180-330 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow W\tilde{t}_1^\dagger$		2-3, ϵ, μ	0	Yes	20.3	$m(\tilde{\chi}_1^0) > 420 \text{ GeV}$
$\tilde{t}_1\tilde{t}_2, \tilde{t}_2 \rightarrow W\tilde{t}_1^\dagger$	1, ϵ, μ	2 b	Yes	20.3	$m(\tilde{\chi}_1^0) > 285 \text{ GeV}$	
Long-lived particles	Direct \tilde{t}_1, \tilde{t}_2 prod., long-lived \tilde{t}_1^\dagger	Disapp. trk	1 jet	Yes	20.3	$m(\tilde{\chi}_1^0) > 270 \text{ GeV}$
	Stable, stopped \tilde{t}_1 R-hadron	0	1-5 jets	Yes	22.9	$m(\tilde{\chi}_1^0) > 832 \text{ GeV}$
	GMSB stable $\tilde{t}_1, \tilde{t}_1^\dagger \rightarrow (\tilde{t}_1, \tilde{\mu}) \rightarrow \tau, \nu, \nu$	1, 2, μ	-	-	15.9	$m(\tilde{\chi}_1^0) > 475 \text{ GeV}$
	GMSB, $\tilde{t}_1^\dagger \rightarrow \nu\tilde{\chi}_1^0$, long-lived \tilde{t}_1^\dagger	1, μ , displ. vtx	-	-	20.3	$m(\tilde{\chi}_1^0) > 230 \text{ GeV}$
RPV	LFV $\tilde{g}\tilde{g} \rightarrow \tilde{g} + X, \tilde{t}_1 \rightarrow \tau + e + \mu$	2, ϵ, μ, τ	-	-	4.6	$\tilde{\chi}_1^0 \rightarrow 0, \tilde{t}_1 \rightarrow 0.05$
	LFV $\tilde{g}\tilde{g} \rightarrow \tilde{g} + X, \tilde{t}_1 \rightarrow \tau + e + \mu + \tau$	1, ϵ, μ, τ	-	-	4.6	$\tilde{\chi}_1^0 \rightarrow 0, \tilde{t}_1 \rightarrow 0.05$
	Bilinear RPV CMSSM	1, ϵ, μ	7 jets	Yes	4.7	$m(\tilde{\chi}_1^0) = 0, \epsilon_{12,21} < 1 \text{ mm}$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^\dagger, \tilde{t}_1^\dagger \rightarrow \tau\nu\tilde{\chi}_1^0$	4, ϵ, μ	-	Yes	20.7	$m(\tilde{\chi}_1^0) > 300 \text{ GeV}, \tilde{t}_1 \rightarrow 0$
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{t}_1^\dagger, \tilde{t}_1^\dagger \rightarrow \tau\nu\tilde{\chi}_1^0$	3, ϵ, μ, τ	-	Yes	20.7	$m(\tilde{\chi}_1^0) > 80 \text{ GeV}, \tilde{t}_1 \rightarrow 0$
	$\tilde{g}\tilde{g} \rightarrow \tilde{g} + X$	0	6-7 jets	Yes	20.3	$\text{BR}(\tilde{\chi}_1^0) > \text{BR}(\tilde{\tau}^{\pm}) > 0\%$
	$\tilde{g}\tilde{g} \rightarrow \tilde{g} + X$	2, ϵ, μ (SS)	0-3 b	Yes	20.7	$m(\tilde{\chi}_1^0) > 916 \text{ GeV}$
	Scalar gluon pair, sgluon $\rightarrow \tilde{q}\tilde{q}$	0	4 jets	-	4.6	incl. limit from 110.2693
	Scalar gluon pair, sgluon $\rightarrow \tilde{t}\tilde{t}$	2, ϵ, μ (SS)	2 b	-	14.3	$m(\tilde{\chi}_1^0) > 350-300 \text{ GeV}$
	WIMP interaction (DS, Dirac χ)	0	mono-jet	Yes	10.5	$m(\tilde{\chi}_1^0) > 80 \text{ GeV}$, limit of $\sim 687 \text{ GeV}$ for DS

$\sqrt{s} = 7 \text{ TeV}$ full data
 $\sqrt{s} = 8 \text{ TeV}$ partial data
 $\sqrt{s} = 8 \text{ TeV}$ full data

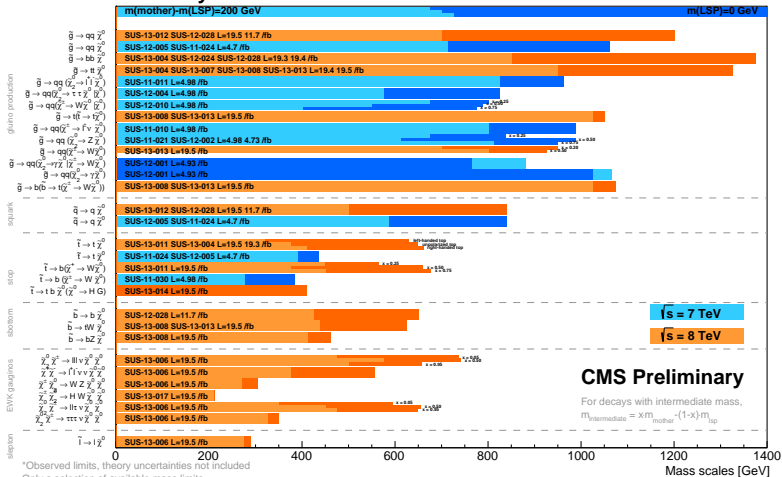
Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 σ theoretical signal cross section uncertainty.

SUMMARY OF SEARCHES FOR SUSY-CMS

Summary of CMS SUSY Results* in SMS framework

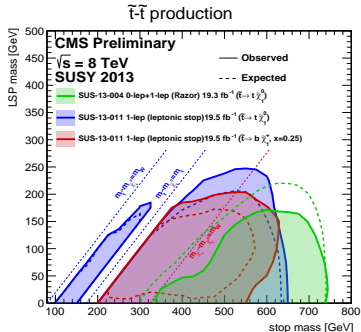
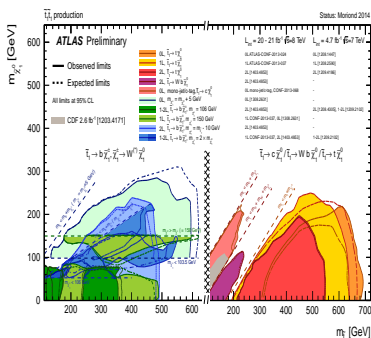
SUSY 2013



*Observed limits, theory uncertainties not included
 Only a selection of available mass limits
 Probe *up to* the quoted mass limit

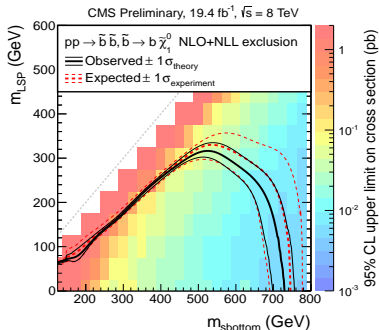
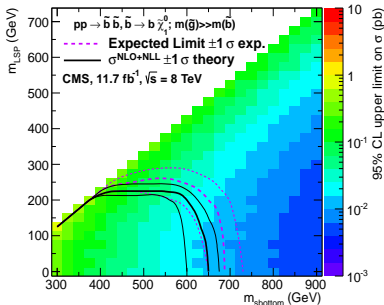
SUMMARY OF SEARCHES FOR SUSY-STOP

- Essential particle for SUSY naturalness
- Suppressed production rates vs. other coloured particles at LHC
 - s -channel gluon and t -channel \tilde{t} exchange
 - p -wave suppressed as final state need angular momentum
 - direct production $\sigma \sim 10 \text{ pb} - 1 \text{ fb}$ for $m_{\tilde{t}} \sim 200 - 900 \text{ GeV}$.
- Final states difficult to disentangle from $t\bar{t}$ backgrounds; current reach $\sim 650 \text{ GeV}$ at 10 fb.



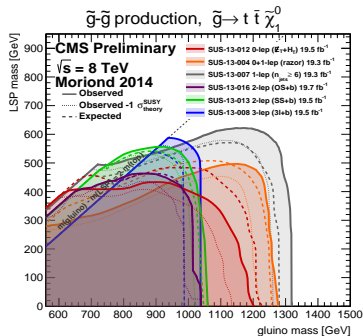
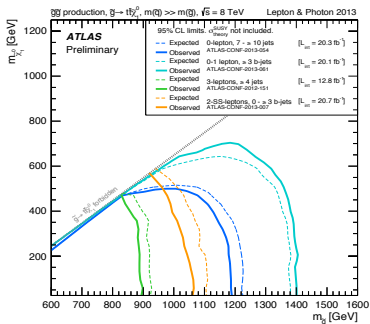
SUMMARY OF SEARCHES FOR SUSY-SBOTTOM

- Complimentary to stop searches
- Though is not as important as stop in naturalness, expect that as part of same doublet, same soft masses
 - production and decay rates are similar, slight relative enhancement due to electroweak corrections
 - complementary decay modes
 - direct production $\sigma \sim 10 \text{ pb} - 1 \text{ fb}$ for $m_{\tilde{b}} \sim 200-900 \text{ GeV}$.
- Final states also difficult to disentangle from $t\bar{t}$ backgrounds; current reach $\sim 600 \text{ GeV}$ at 10 fb.



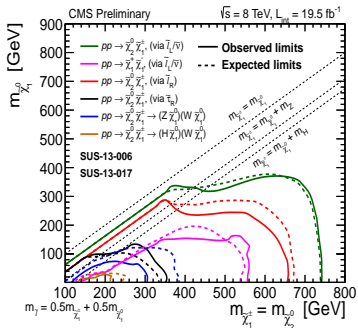
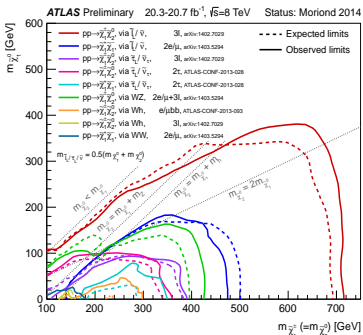
SUMMARY OF SEARCHES FOR SUSY-GLUINO

- Driving forces of SUSY signals at the LHC
- Considerable production rates vs. other coloured particles at LHC
 - pair production cross section $\sim \times 2$ that for stops
 - direct production from $\sigma \sim 10 \text{ pb} - 1 \text{ fb}$ for $m_{\tilde{t}} \sim 400\text{-}1300 \text{ GeV}$
 - if squarks are heavier ("pure gluino") decay into 3-bodies $\tilde{g} \rightarrow q\bar{q}\chi_1^0$, into final states with high jet multiplicity $\gtrsim 4j$
 - limits reach $\sim 1.2 \text{ TeV}$ from leptonic, or b -quark final states.



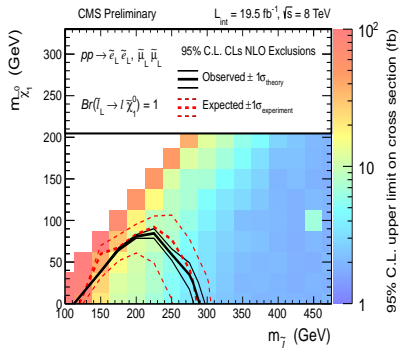
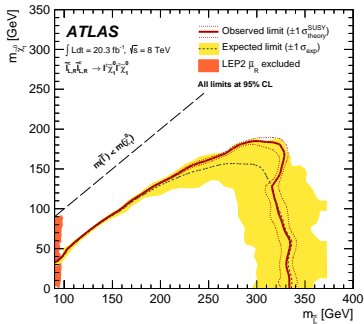
SUMMARY OF SEARCHES—ELECTROWEAKINOS

- Expected to be the lightest SUSY particles in most scenarios.
- Challenging searches, substantial background from SM di-boson production:
 - most effective channels are trileptons including one OSSF pair (sensitivity \sim few fb)
 - also $2\ell + 2j$ final states;
 - sensitivity to cross section BR \sim 10 fb;
 - limits reach $m_{\chi_2^0, \chi_1^\pm} \gtrsim 325$ GeV for LSP masses lower than 70 GeV.



SUMMARY OF SEARCHES FOR SUSY-SLEPTONS

- Direct limits on pair production through EW processes better than LEP
- Cross sections of \sim few fb
- Current reach \sim 275 GeV for left-handed leptons only; \sim 300 GeV for degenerate \tilde{L}_L and \tilde{L}_R .



RESTRICTIONS FROM THE HIGGS DATA

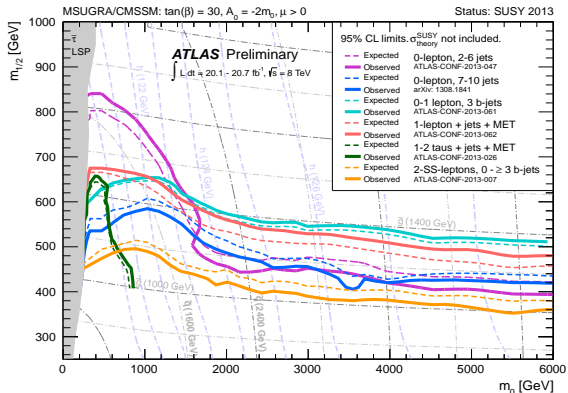
$$m_h^2 = m_Z^2 \cos^2(2\beta) + \frac{3m_t^4}{4\pi^2 v^2} \left[\ln \left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \right) + \frac{(A_t - \mu \cot \beta)^2}{m_{\tilde{t}_1} m_{\tilde{t}_2}} \left(1 - \frac{(A_t - \mu \cot \beta)^2}{12 m_{\tilde{t}_1} m_{\tilde{t}_2}} \right) \right]$$

- Higgs mass has difficulties with respect to minimal predictions, requiring a correction of the same size as minimal tree-level contribution.
 - If radiative effects are unimportant $m_h < m_Z$. [But $m_h^2 = m_Z^2$, problems with Veltman Condition].
 - If the ln is large, without stop mixing, $\sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} \gtrsim 4$ TeV.
 - With stop mixing, one must close-tune $A_t - \mu \cot \beta \approx \pm \sqrt{6 m_{\tilde{t}_1} m_{\tilde{t}_2}}$.
 - Enhancing tree-level contributions to m_h from F and D terms yields $\tan \beta = 1$.
 - Enhance loop level m_h from additional matter multiplets.
- Explaining the Higgs mass in MSSM involves tuning the log enhanced and finite corrections.
- Coupling measurements impose useful constraints for light sparticles only.

SUMMARY OF SEARCHES FOR SUSY-MSUGRA

MSUGRA/CMSSM

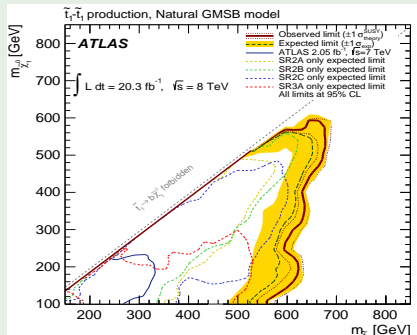
- Supersymmetry is broken *universally* by the gravity sector in the model.
- LSP χ_1^0 is generally bino-like \tilde{B} .
- Only 5 parameters $m_{1/2}$, m_0 , $\tan\beta$, A_0 and $\text{sign}(\mu)$.
- Mass difference between the LSP and squarks and gluinos is large.



SUMMARY OF SEARCHES FOR GMSB

GMSB

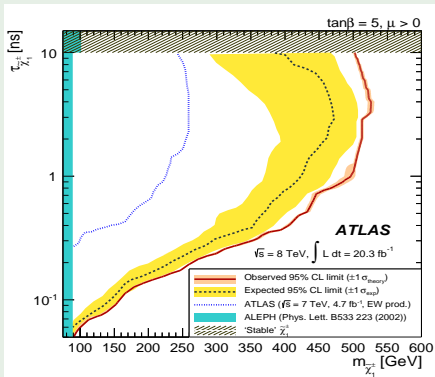
- Supersymmetry is broken by the gauge sector in the model, which being flavour blind, avoids SUSY flavour violation.
 - Has an observable sector, usual quarks, leptons, and superpartners.
 - Has a secluded sector, responsible for symmetry breaking (X, goldstino).
 - Has a messenger sector, new fields which couple to X
- LSP χ_1^0 is always the gravitino \tilde{G} , with the NLSP a slepton, chargino or neutralino.



SUMMARY OF SEARCHES FOR AMSB

AMSB

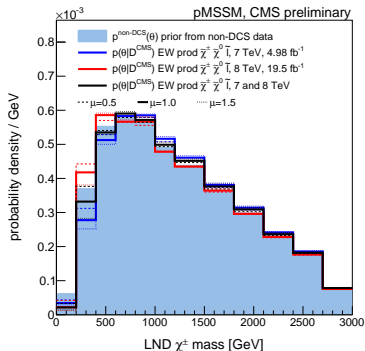
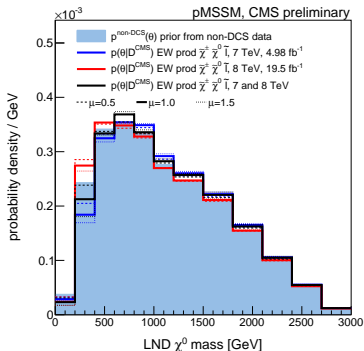
- Soft SUSY broken by loop effects, all soft SUSY breaking parameters are determined by the $m_{3/2}$ and anomalous dimensions at EW scale.
- LSP χ_1^0 in general neutral wino \tilde{W}^0 , mass degenerate with \tilde{W}^\pm .
- χ_1^\pm only slightly heavier than χ_1^0 , χ_1^\pm long lived, and $\chi_1^\pm \rightarrow \chi_1^0 \pi^\pm$.



SUMMARY OF SEARCHES FOR PMSSM

PMSSM

- Assumes absence of FCNC, CP violation and universality of the first and second generation;
- Reduces the number of MSSM parameters to 19;
- Sensitivity of searches to configurations of SUSY masses and branching ratios can be assessed.



COULD SUSY STILL BE HIDING SOMEWHERE?

THE SIGNAL IS NOT WHAT WE EXPECT

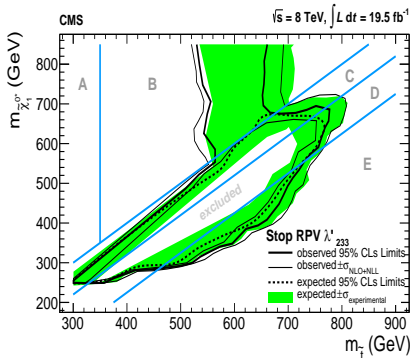
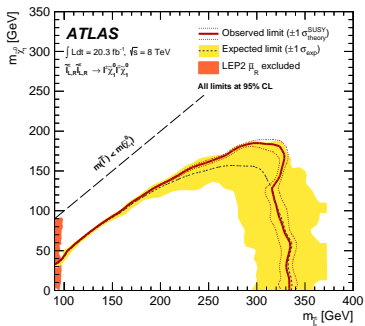
- No large missing transverse energy associated with decays of heavy states into the LSP;
- Suppress large hadronic activity associated with heavier mass scales.
 - **Compressed SUSY** (no significant separation between colored and uncolored particles);
 - **RPV SUSY** [$R = (-1)^{3B+L+2s}$]

R-PARITY VIOLATION

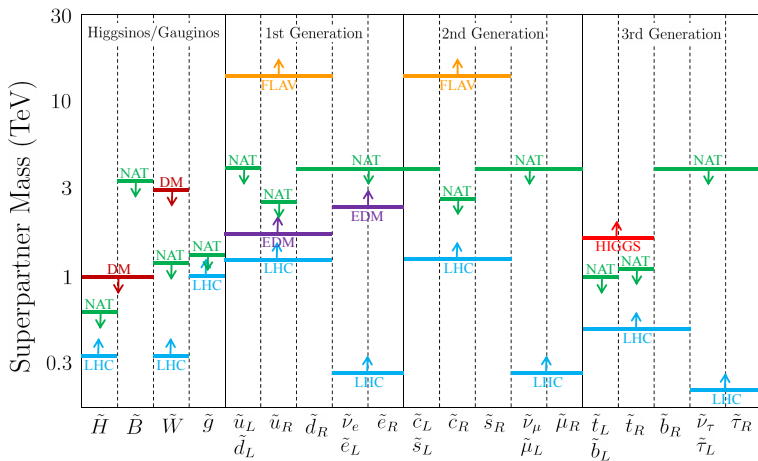
$$W_{\text{RPV}} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k.$$

- Models accommodate neutrino masses and oscillations.
- Assume either λ_{ijk} , λ'_{ijk} or λ''_{ijk} are 0, so no proton decay.
- Pair production of superpartners no longer necessary, thus typical signal does not show missing energy.
- LSP unstable, can have colour and electric charge.

R-PARITY VIOLATION



CONSTRAINTS FROM NATURALNESS



[1302.6587]

COULD SUSY STILL BE HIDING SOMEWHERE?

THE SPECTRUM IS NOT WHAT WE EXPECT

Non-minimal models which live in parameter spaces less contained by LHC limits.

- **Single Sector SUSY breaking** (flavour and soft-spectrum arising from the same source, strong dynamics, with light fermion generations identified with bound states of the strong dynamics);
- **Split families** (first two generations are charged under a different set of SM gauge groups at high energies);
- **Flavor mediation** (supersymmetry breaking through spontaneously broken through a gauged flavour symmetry yielding the observed pattern of fermion masses and mixings);
- **Colourless SUSY** (top partners do not carry QCD charges at low energies—no strong production modes, eroding limits on stop masses);
- **Focus Point SUSY** (eliminate radiatively the sensitivity of EW scales to soft masses by allowing large soft masses but small radiative effects).

CONCLUSION

- Physicists very successful at discovering good/correct models:
 - Standard Model (electroweak and strong);
 - Higgs Mechanism;
 - neutrino seesaw;
- But bad track guessing the correct parameters
 - top Mass;
 - neutrino masses and mixing;
 - V_{cb} .



- Supersymmetry remains the most promising BSM scenario:
 - consistent and completely formulated models working to GUT scales;
 - computable framework up to M_{Planck} ;
 - consistent with coupling unification and proton decay bounds;
 - provide a DM candidate;
 - and eminently testable at the LHC,
- but we may be not looking in the right region, that is
we were wrong about how SUSY would be detected at the LHC.

SUSY ALREADY SEEN?

- $W^\pm W^\mp$ cross section $\sim 20\%$ higher than theoretical predictions ($1 - 2\sigma$ excess);
- SUSY searches for 3 leptons show $1.6 - 2.1\sigma$ excess;
- SUSY searches for squarks and gluinos show $\sim 2.5\sigma$ excess.

A SUSY MODEL WITH A LIGHT STOP ($m_{\tilde{t}_1} \sim 212$ GEV), LIGHT WINOS AND LIGHT BINOS ($m_{\chi_1^0} \sim 150$ GEV) CAN MATCH THE DATA .

[1406.0858]