

# The Future of Supersymmetry

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**...in recent times,**

**supersymmetry**

**has been getting a lot of bad press**

**Supersymmetry Bites the Dust**

**Where Supersymmetry Belongs: In a Coffin**

**SUSY in the Hospital?**

**Is Supersymmetry Dead?**

**“Supersymmetry Dealt a Blow”?**

**Well that about wraps it up for *SUSY*?**

**Truant particles turn the screw on supersymmetry**

**Supersymmetry takes an arrow to the knee**

**Is SUSY Dead Yet?**

**The uncertain future of SUSY**

# The Future of Supersymmetry

... is rooted in the present

# THE CASE FOR SUSY

## Aesthetic appeal of SUSY:

- only way of combining spacetime symmetry w. internal symmetry  
⇒ the only way to combine gravity with other interactions
- only theory which explains differentiation of bosons and fermions  
⇒ a consequence of the breaking of supersymmetry

## Practical appeal of SUSY:

- most natural way of solving hierarchy problem  
⇒ pairwise cancellation of quadratic divergences
- only theory where a light Higgs boson is predicted naturally  
⇒ fits the 125 GeV Higgs boson perfectly
- only theory which has a natural dark matter candidate  
⇒ and also has a 'solution' for the cosmological constant
- electroweak symmetry-breaking has a dynamical origin
- only way to get gauge coupling unification with one-step breaking

# Group Theoretic Arguments

## The Coleman-Mandula no-go theorem

If  $\mathfrak{G}$  is a symmetry group of the S-Matrix, and the following assumptions hold:

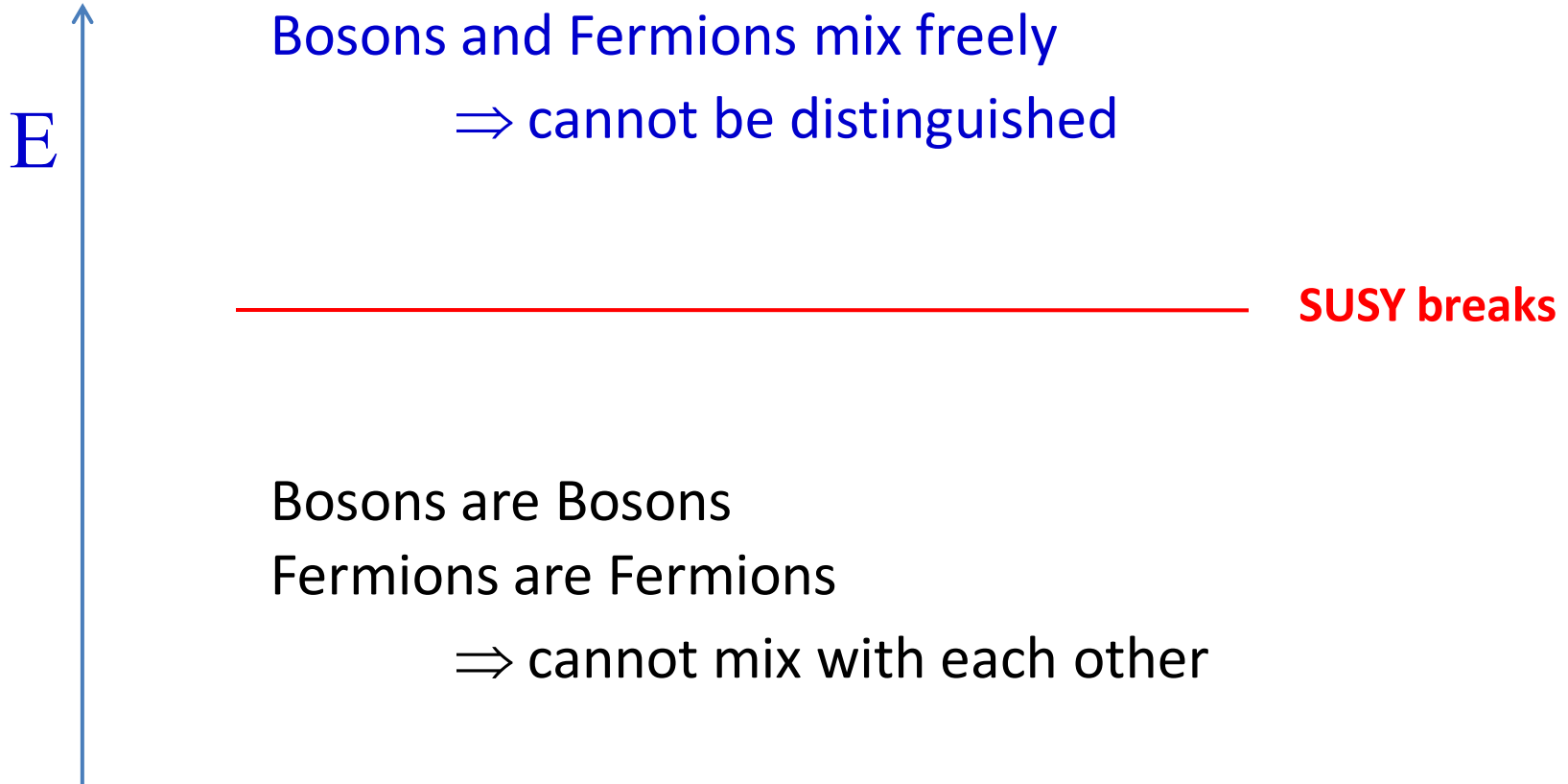
1. For any  $M$  there are only a finite number of particle types with mass less than  $M$ ,
2. Scattering occurs at almost all energies (except for perhaps some isolated set of energies),
3. The amplitudes for elastic two-body scattering are analytic functions of the scattering angle at almost all energies and angles,

then the generators of  $\mathfrak{G}$  consist of only the generators of the Poincaré group  $\mathfrak{P}$ , and the generators of internal symmetries.

## Haag–Lopuszanski–Sohnius theorem

The only way to evade the restrictions of the Coleman-Mandula theorem is to replace the Lie group of symmetries by a  $Z_2$  graded Lie group  
 $\Rightarrow$  supersymmetry

$$\{Q_\alpha, \bar{Q}_{\dot{\beta}}\} = 2(\sigma^\mu)_{\alpha\dot{\beta}} P_\mu$$



Spin-statistics theorem becomes a low-energy effect

## Mass Stabilization Arguments

Standard Model with  $f = t$  :

$$m_h^2 \approx m_{h0}^2 - \frac{\lambda_f^2}{8\pi^2} N_c^f \int^\Lambda \frac{d^4 p}{p^2} \approx m_{h0}^2 + \frac{\lambda_f^2}{8\pi^2} N_c^f \Lambda^2$$

$$\mathcal{N}^0 \equiv \frac{m_{h0}^2 \text{ 1-loop}}{m_h^2} \sim 10^{30}$$

Supersymmetry with  $f = t$  :


$$m_h^2 \approx m_{h0}^2 + \frac{\lambda_f^2}{8\pi^2} N_c^f \left( \cancel{m_{\tilde{f}}^2} - \cancel{m_f^2} \right) \ln \left( \Lambda^2 / m_{\tilde{f}}^2 \right)$$

$$m_{\tilde{f}} \lesssim 800 \text{ GeV} \frac{1.0}{\lambda_f} \left[ \frac{3}{N_c^f} \right]^{\frac{1}{2}} \left[ \frac{70}{\ln(\Lambda^2 / m_{\tilde{f}}^2)} \right]^{\frac{1}{2}} \left[ \frac{\mathcal{N}_{\text{max}}^0}{100} \right]^{\frac{1}{2}}$$




## Light Higgs Boson Arguments


$$m_{h^0}^2 = m_Z^2 \cos^2(2\beta) + \frac{3}{4\pi^2} \sin^2\beta y_t^2 \left[ m_t^2 \ln(m_{\tilde{t}_1} m_{\tilde{t}_2} / m_t^2) + c_t^2 s_t^2 (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2) \ln(m_{\tilde{t}_2}^2 / m_{\tilde{t}_1}^2) \right. \\ \left. + c_t^4 s_t^4 \left\{ (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2)^2 - \frac{1}{2} (m_{\tilde{t}_2}^4 - m_{\tilde{t}_1}^4) \ln(m_{\tilde{t}_2}^2 / m_{\tilde{t}_1}^2) \right\} / m_t^2 \right].$$



91 GeV



113 +... GeV



135 GeV max

Discovery of a 123 – 127 GeV Higgs-like boson vindicates what SUSY has always predicted

$$\textcircled{h^0}, H^0, A^0, H^+, H^-$$

Large stop mass splitting required...

## Dark Matter Arguments

Lepton number (L) and baryon number (B) conservation in the Standard Model are purely accidental – they happen because we write the minimum number of possible operators

Any bigger symmetry, such as a GUT, will automatically violate these U(1) global symmetries and lead to rapid proton decay

SUSY models lend themselves naturally to a global U(1) R-symmetry. When SUSY breaks, this remains as R-parity

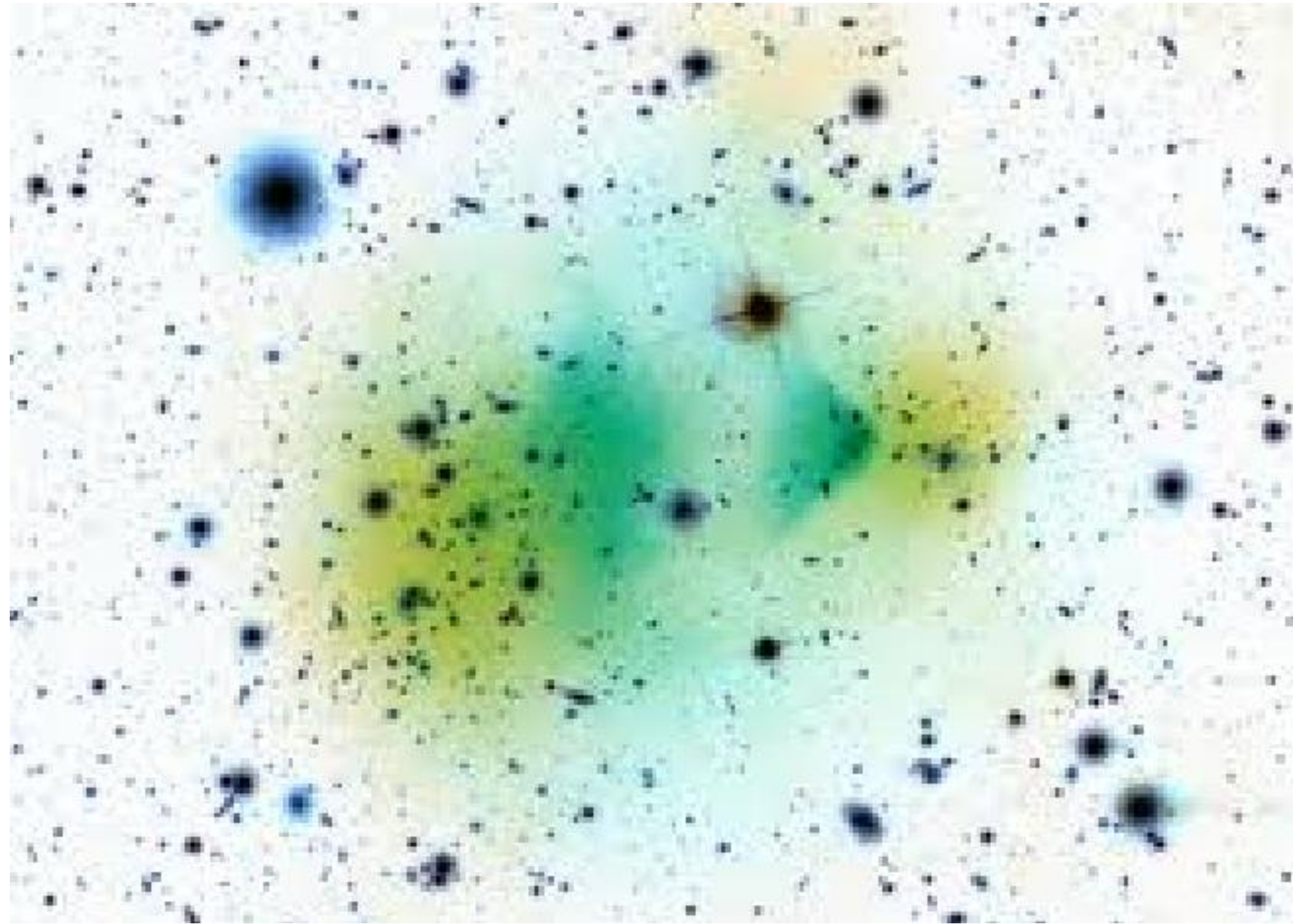
$$(-)^{L+2S+3B}$$

All SM particles have R-parity +1, all SUSY partners have -1

⇒ The LSP is stable and weakly interacting

⇒ ideal WIMP for dark matter candidate

Dark matter must be WIMPS.... Bullet Cluster....



# Electroweak Symmetry Breaking in SUSY

S.P. Martin  
hep-ph/9709256

$$V = (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_d^0|^2 - (b H_u^0 H_d^0 + \text{c.c.}) + \frac{1}{8}(g^2 + g'^2)(|H_u^0|^2 - |H_d^0|^2)^2.$$

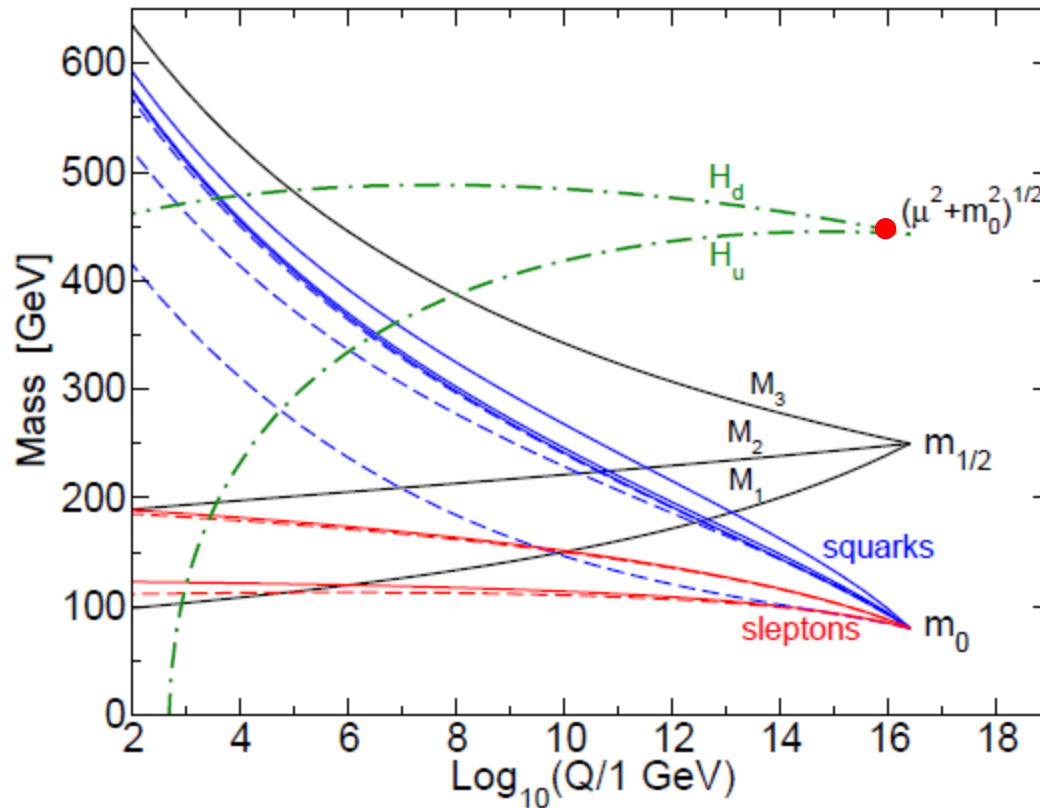
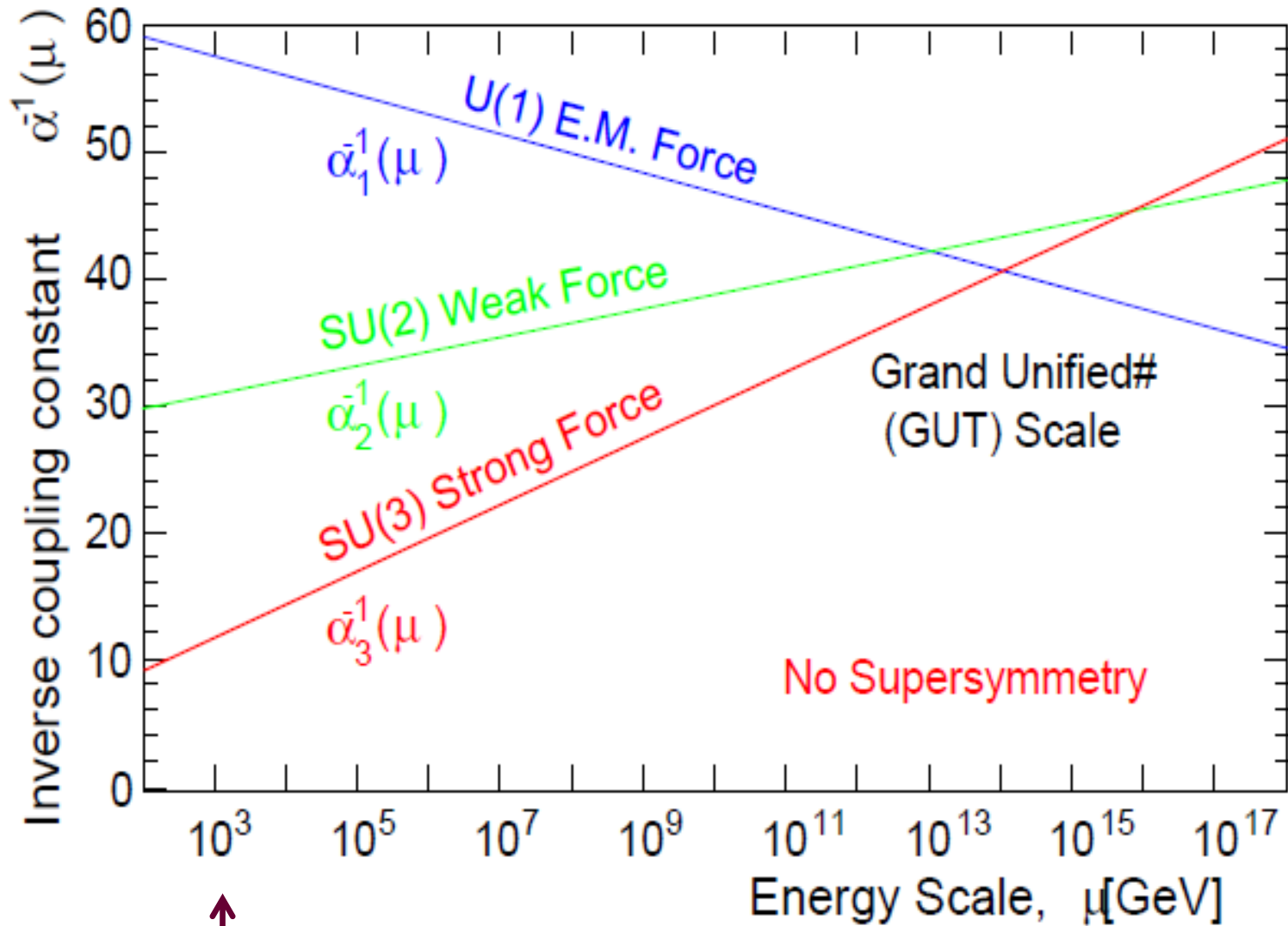


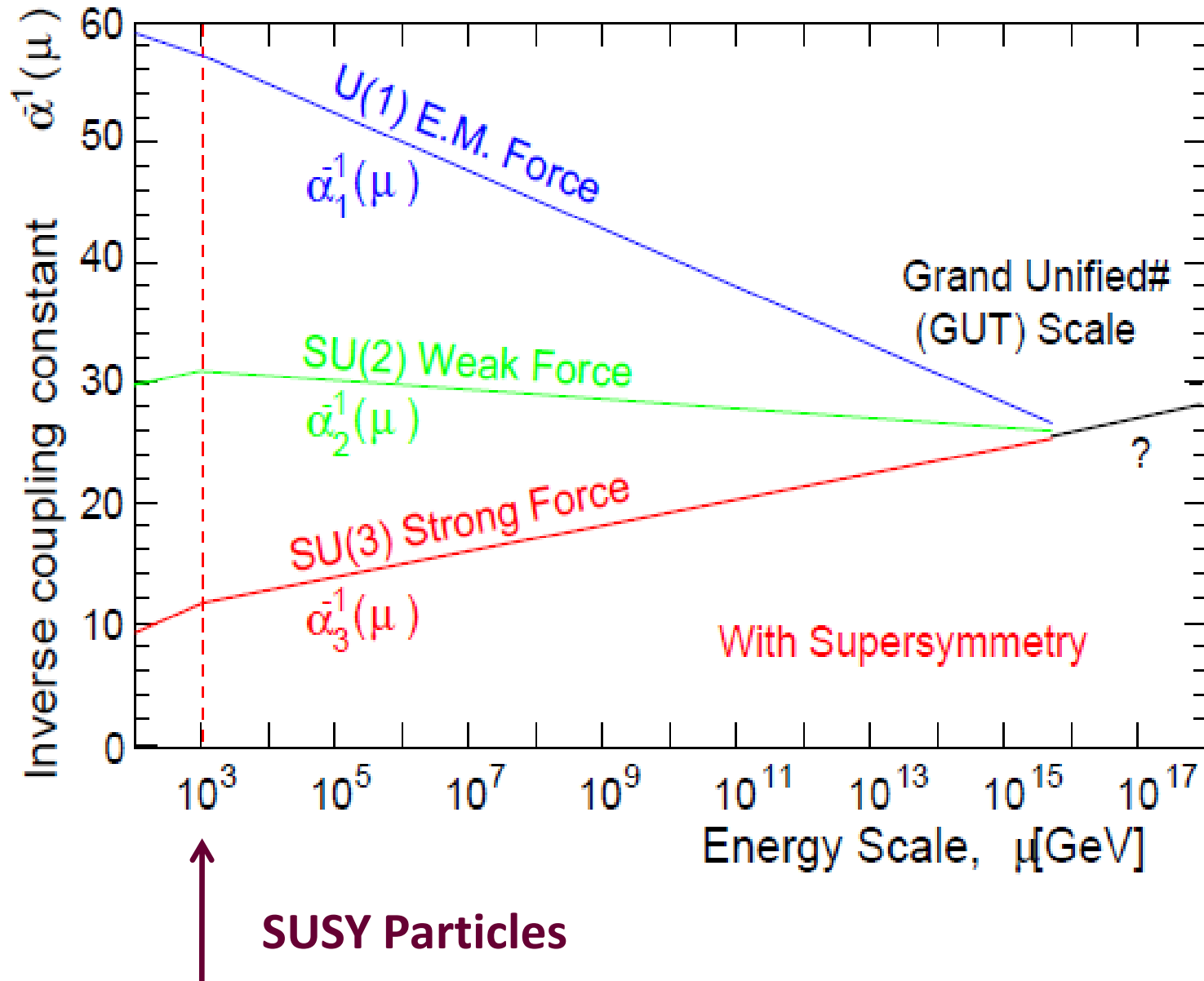
Figure 7.4: RG evolution of scalar and gaugino mass parameters in the MSSM with typical minimal supergravity-inspired boundary conditions imposed at  $Q_0 = 2.5 \times 10^{16}$  GeV. The parameter  $\mu^2 + m_{H_u}^2$  runs negative, provoking electroweak symmetry breaking.

# Gauge Coupling Unification in SUSY



**SUSY Particles**

# Gauge Coupling Unification in SUSY



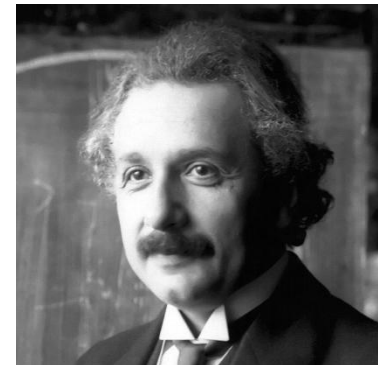
# Such a beautiful theory must have truth in it somewhere



Dr. Einstein, it seems that the observations made by the British team of the recent solar eclipse in South America support your theory of general relativity.

How would you have felt if your theory had been proven wrong?

Then I would have felt sorry for the Lord.  
The theory is correct.

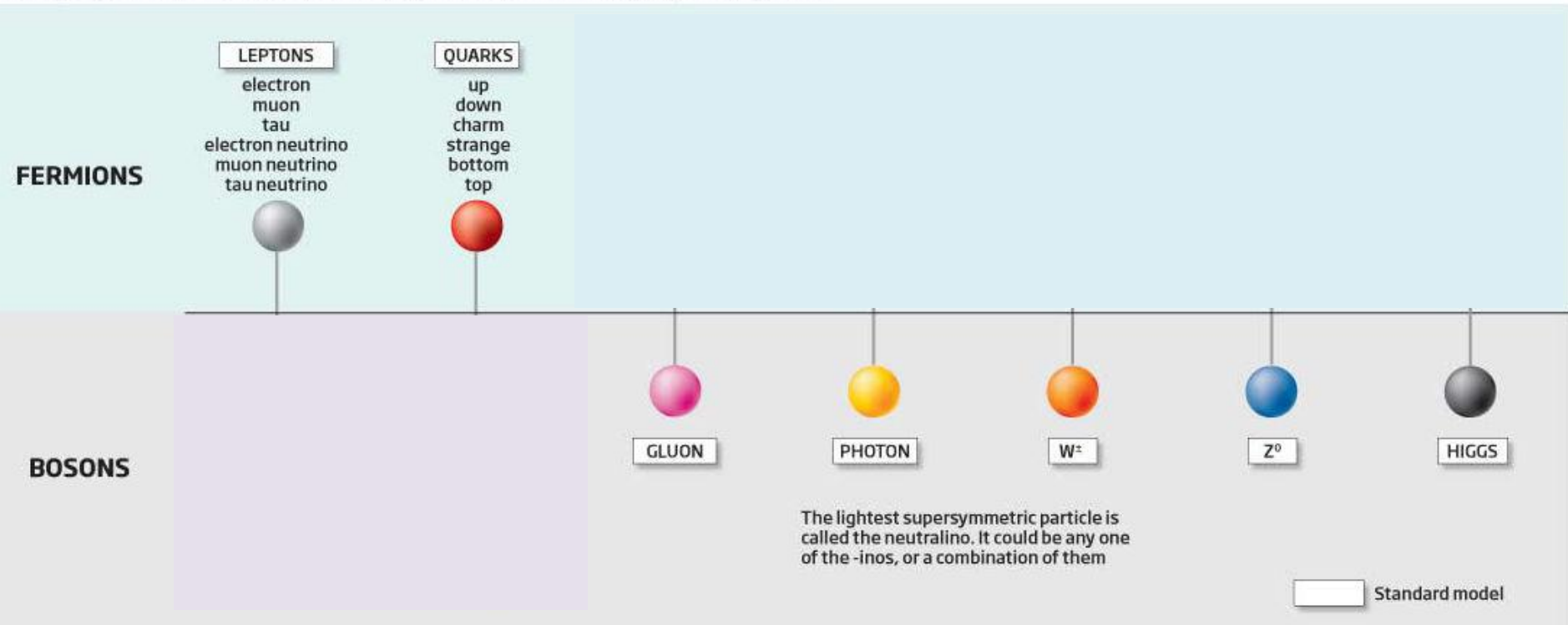


# The Only Problem...

## Particle zoo

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Particles are divided into two families called bosons and fermions. Among them are groups known as leptons, quarks and force-carrying particles like the photon. Supersymmetry doubles the number of particles, giving each fermion a massive boson as a super-partner and vice versa. The LHC is expected to find the first supersymmetric particle



...we have no experimental evidence at all for SUSY particles

...okay, then they must be heavy...



# ATLAS SUSY Searches\* - 95% CL Lower Limits (Status: Dec 2012)

**ATLAS**  
Preliminary

$\int L dt = (2.1 - 13.0) \text{ fb}^{-1}$   
 $\sqrt{s} = 7, 8 \text{ TeV}$

**Inclusive searches**  
 MSUGRA/CMSSM : 0 lep + j's +  $E_{T,miss}$   
 MSUGRA/CMSSM : 1 lep + j's +  $E_{T,miss}$   
 Pheno model : 0 lep + j's +  $E_{T,miss}$   
 Pheno model : 0 lep + j's +  $E_{T,miss}$   
 Gluino med.  $\tilde{\chi}^{\pm}$  ( $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^{\pm}$ ) : 1 lep + j's +  $E_{T,miss}$   
 GMSB ( $\tilde{l}$  NLSP) : 2 lep (OS) + j's +  $E_{T,miss}$   
 GMSB ( $\tilde{\tau}$  NLSP) : 1-2  $\tau$  + 0-1 lep + j's +  $E_{T,miss}$   
 GGM (bino NLSP) :  $\gamma\gamma$  +  $E_{T,miss}$   
 GGM (wino NLSP) :  $\gamma$  + lep +  $E_{T,miss}$   
 GGM (higgsino-bino NLSP) :  $\gamma$  + b +  $E_{T,miss}$   
 GGM (higgsino NLSP) : Z + jets +  $E_{T,miss}$   
 Gravitino LSP : 'monojet' +  $E_{T,miss}$

**3rd gen. sq. gluino med.**  
 $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$  (virtual b) : 0 lep + 3 b-j's +  $E_{T,miss}$   
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$  (virtual t) : 2 lep (SS) + j's +  $E_{T,miss}$   
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$  (virtual t) : 3 lep + j's +  $E_{T,miss}$   
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$  (virtual t) : 0 lep + multi-j's +  $E_{T,miss}$   
 $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$  (virtual t) : 0 lep + 3 b-j's +  $E_{T,miss}$

**3rd gen. squarks direct production**  
 $bb, b_1 \rightarrow b\tilde{\chi}_1^{\pm}$  : 0 lep + 2-b-jets +  $E_{T,miss}$   
 $\tilde{b}\tilde{b}, \tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm}$  : 3 lep + j's +  $E_{T,miss}$   
 $\tilde{t}$  (light),  $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}$  : 1/2 lep (+ b-jet) +  $E_{T,miss}$   
 $\tilde{t}$  (medium),  $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}$  : 1 lep + b-jet +  $E_{T,miss}$   
 $\tilde{t}$  (medium),  $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm}$  : 2 lep +  $E_{T,miss}$

**3rd gen. direct**  
 $\tilde{t}\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0$  : 1 lep + b-jet +  $E_{T,miss}$   
 $\tilde{t}\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0$  : 0/1/2 lep (+ b-jets) +  $E_{T,miss}$   
 $\tilde{t}\tilde{t}$  (natural GMSB) : Z( $\rightarrow ll$ ) + b-jet +  $E_{T,miss}$

**EW direct**  
 $l_1 l_1, l \rightarrow l\tilde{\chi}_1^0$  : 2 lep +  $E_{T,miss}$   
 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow l\nu(\bar{\nu}) \rightarrow l\nu\tilde{\chi}_1^0$  : 2 lep +  $E_{T,miss}$   
 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\pm} \rightarrow l\nu(\bar{\nu})l(\bar{\nu}\nu), |\bar{\nu}\nu|l(\bar{\nu}\nu)$  : 3 lep +  $E_{T,miss}$   
 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\pm} \rightarrow W\nu\tilde{\chi}_1^0, Z\nu\tilde{\chi}_1^0$  : 3 lep +  $E_{T,miss}$

**Long-lived particles**  
 Direct  $\tilde{\chi}_1^{\pm}$  pair prod. (AMSB) : long-lived  $\tilde{\chi}_1^{\pm}$   
 Stable  $\tilde{g}$  R-hadrons : low  $\beta, \beta\gamma$  (full detector)  
 Stable  $\tilde{t}$  R-hadrons : low  $\beta, \beta\gamma$  (full detector)  
 GMSB : stable  $\tilde{\tau}$

**RPV**  
 $\tilde{\chi}_1^0 \rightarrow qq\mu$  (RPV) :  $\mu$  + heavy displaced vertex  
 LFV :  $pp \rightarrow \tilde{\nu}_e + X, \tilde{\nu}_e \rightarrow e + \mu$  resonance  
 LFV :  $pp \rightarrow \tilde{\nu}_e + X, \tilde{\nu}_e \rightarrow e(\mu) + \tau$  resonance  
 Bilinear RPV CMSSM : 1 lep + 7 j's +  $E_{T,miss}$   
 $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\pm} \rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow e\nu_{\mu}, e\nu_{\tau}$  : 4 lep +  $E_{T,miss}$   
 $l_1 l_1, l_1 \rightarrow \tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{\pm} \rightarrow e\nu_{\mu}, e\nu_{\tau}$  : 4 lep +  $E_{T,miss}$   
 $\tilde{g} \rightarrow qq\bar{q}$  : 3-jet resonance pair  
 Scalar gluon : 2-jet resonance pair  
 WIMP interaction (D5, Dirac  $\tilde{\chi}$ ) : 'monojet' +  $E_{T,miss}$

$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.50 TeV	$\tilde{q} = \tilde{g}$ mass
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-104]	1.24 TeV	$\tilde{q} = \tilde{g}$ mass
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.18 TeV	$\tilde{g}$ mass ( $m(\tilde{q}) < 2 \text{ TeV}$ , light $\tilde{\chi}_1^0$ )
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-109]	1.38 TeV	$\tilde{q}$ mass ( $m(\tilde{g}) < 2 \text{ TeV}$ , light $\tilde{\chi}_1^0$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.4688]	900 GeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 200 \text{ GeV}, m(\tilde{\chi}^{\pm}) = \frac{1}{2}(m(\tilde{\chi}^0) + m(\tilde{g}))$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.4688]	1.24 TeV	$\tilde{g}$ mass ( $\tan\beta < 15$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1210.1314]	1.20 TeV	$\tilde{g}$ mass ( $\tan\beta > 20$ )
$L=4.8 \text{ fb}^{-1}, 7 \text{ TeV}$ [1209.0753]	1.07 TeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) > 50 \text{ GeV}$ )
$L=4.8 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-144]	619 GeV	$\tilde{g}$ mass
$L=4.8 \text{ fb}^{-1}, 7 \text{ TeV}$ [1211.1167]	900 GeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) > 220 \text{ GeV}$ )
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-152]	690 GeV	$\tilde{g}$ mass ( $m(\tilde{H}) > 200 \text{ GeV}$ )
$L=10.5 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-147]	645 GeV	$F^{1/2}$ scale ( $m(\tilde{G}) > 10^4 \text{ eV}$ )
$L=12.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-145]	1.24 TeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 200 \text{ GeV}$ )
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-105]	850 GeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 300 \text{ GeV}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-151]	860 GeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 300 \text{ GeV}$ )
$L=5.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-103]	1.00 TeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 300 \text{ GeV}$ )
$L=12.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-145]	1.15 TeV	$\tilde{g}$ mass ( $m(\tilde{\chi}_1^0) < 200 \text{ GeV}$ )
$L=12.8 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-165]	620 GeV	b mass ( $m(\tilde{\chi}_1^0) < 120 \text{ GeV}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-151]	405 GeV	b mass ( $m(\tilde{\chi}_1^0) = 2m(\tilde{\chi}_1^{\pm})$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.4305, 1209.2102] 67 GeV		$\tilde{t}$ mass ( $m(\tilde{\chi}_1^0) = 55 \text{ GeV}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-166]	160-350 GeV	$\tilde{t}$ mass ( $m(\tilde{\chi}_1^0) = 0 \text{ GeV}, m(\tilde{\chi}_1^{\pm}) = 150 \text{ GeV}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-167]	160-440 GeV	$\tilde{t}$ mass ( $m(\tilde{\chi}_1^0) = 0 \text{ GeV}, m(\tilde{l}) - m(\tilde{\nu}) = 10 \text{ GeV}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-166]	230-560 GeV	$\tilde{t}$ mass ( $m(\tilde{\chi}_1^0) = 0$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.1447, 1208.2590, 1209.4186]	230-465 GeV	$\tilde{t}$ mass ( $m(\tilde{\chi}_1^0) = 0$ )
$L=2.1 \text{ fb}^{-1}, 7 \text{ TeV}$ [1204.6736]	310 GeV	$\tilde{t}$ mass ( $115 < m(\tilde{\chi}_1^0) < 230 \text{ GeV}$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.2884]	85-195 GeV	l mass ( $m(\tilde{\chi}_1^0) = 0$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1208.2884]	110-340 GeV	$\tilde{\chi}_1^{\pm}$ mass ( $m(\tilde{\chi}_1^0) < 10 \text{ GeV}, m(\tilde{\nu}) = \frac{1}{2}(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-154]	580 GeV	$\tilde{\chi}_1^{\pm}$ mass ( $m(\tilde{\chi}_1^0) = m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^{\pm}) = 0, m(\tilde{\nu})$ as above)
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-154]	140-295 GeV	$\tilde{\chi}_1^{\pm}$ mass ( $m(\tilde{\chi}_1^0) = m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^{\pm}) = 0$ , sleptons decoupled)
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1210.2852]	220 GeV	$\tilde{\chi}_1^{\pm}$ mass ( $1 < \tau(\tilde{\chi}_1^{\pm}) < 10 \text{ ns}$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1211.1597]	985 GeV	$\tilde{g}$ mass
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1211.1597]	683 GeV	$\tilde{t}$ mass
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [1211.1597]	300 GeV	$\tilde{\tau}$ mass ( $5 < \tan\beta < 20$ )
$L=4.4 \text{ fb}^{-1}, 7 \text{ TeV}$ [1210.7451]	700 GeV	$\tilde{q}$ mass ( $0.3 \times 10^{-5} < \lambda_{211} < 1.5 \times 10^{-5}, 1 \text{ mm} < c\tau < 1 \text{ m}, \tilde{g}$ decoupled)
$L=4.6 \text{ fb}^{-1}, 7 \text{ TeV}$ [Preliminary]	1.61 TeV	$\tilde{\nu}_{\tau}$ mass ( $\lambda_{311} = 0.10, \lambda_{132} = 0.05$ )
$L=4.6 \text{ fb}^{-1}, 7 \text{ TeV}$ [Preliminary]	1.10 TeV	$\tilde{\nu}_{\tau}$ mass ( $\lambda_{311} = 0.10, \lambda_{121,133} = 0.05$ )
$L=4.7 \text{ fb}^{-1}, 7 \text{ TeV}$ [ATLAS-CONF-2012-140]	1.2 TeV	$\tilde{q} = \tilde{g}$ mass ( $c\tau_{LSP} < 1 \text{ mm}$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-153]	700 GeV	$\tilde{\chi}_1^{\pm}$ mass ( $m(\tilde{\chi}_1^0) > 300 \text{ GeV}, \lambda_{121}$ or $\lambda_{122} > 0$ )
$L=13.0 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-153]	430 GeV	l mass ( $m(\tilde{\chi}_1^0) > 100 \text{ GeV}, m(\tilde{l}_e) = m(\tilde{l}_\mu) = m(\tilde{l}_\tau), \lambda_{121}$ or $\lambda_{122} > 0$ )
$L=4.6 \text{ fb}^{-1}, 7 \text{ TeV}$ [1210.4813]	666 GeV	$\tilde{g}$ mass
$L=4.6 \text{ fb}^{-1}, 7 \text{ TeV}$ [1210.4826]	100-287 GeV	sgluon mass (incl. limit from 1110.2693)
$L=10.5 \text{ fb}^{-1}, 8 \text{ TeV}$ [ATLAS-CONF-2012-147]	704 GeV	$M^*$ scale ( $m_{\tilde{\chi}} < 80 \text{ GeV}$ , limit of $< 687 \text{ GeV}$ for DB)

8 TeV results  
7 TeV results

10<sup>-1</sup> 1 10  
Mass scale [TeV]

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

# Little Hierarchy Problem in 3<sup>rd</sup> generation

$$m_{\tilde{f}} \lesssim 800 \text{ GeV}$$

$$\left[ \frac{\mathcal{N}_{\text{max}}^0}{100} \right]^{\frac{1}{2}}$$

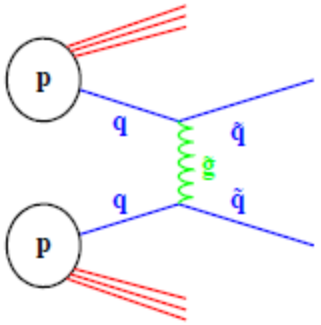
SUSY around  
the corner

$N^0$	<i>Fine tuning level</i>	<i>Max squark mass</i>
<b>10</b>	<b>10%</b>	<b>253 GeV</b>
<b>100</b>	<b>1%</b>	<b>800 GeV</b>
1 000	0.1%	2.53 TeV
10 000	0.01%	8 TeV
100 000	0.001%	25.3 TeV
1 000 000	0.000 1%	80 TeV

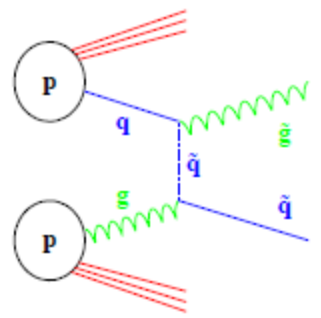
$$\mathcal{N}^0 \equiv \frac{m_h^2 \text{ 1-loop}}{m_h^2}$$

No reason to panic at this stage

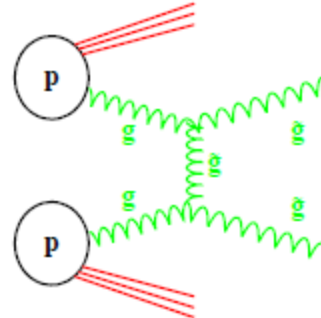
# Collider Searches for SUSY : missing pT



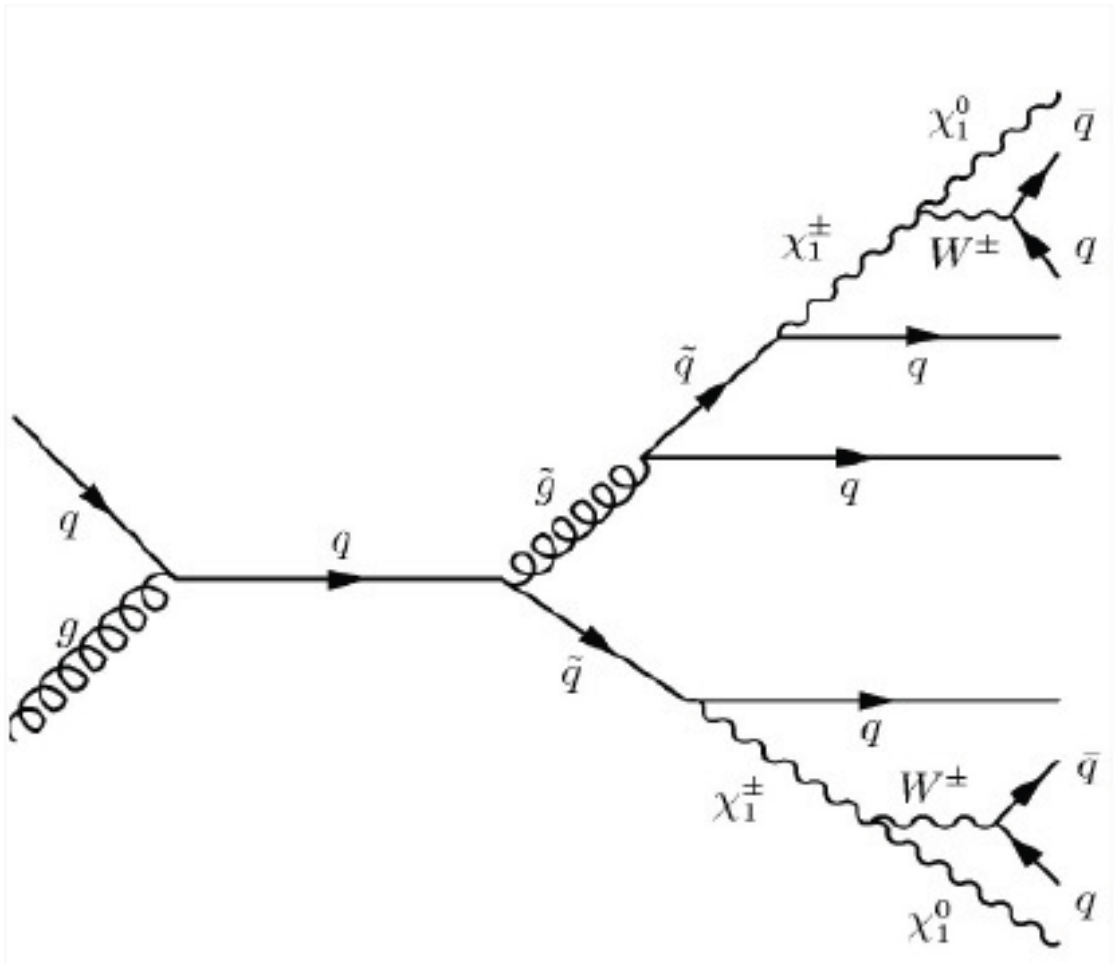
$\tilde{q}\tilde{q}$



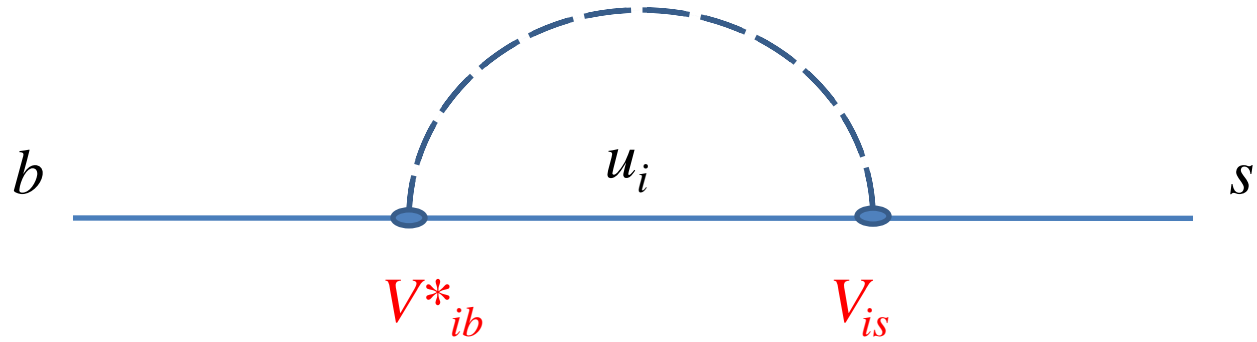
$\tilde{q}\tilde{g}$



$\tilde{g}\tilde{g}$



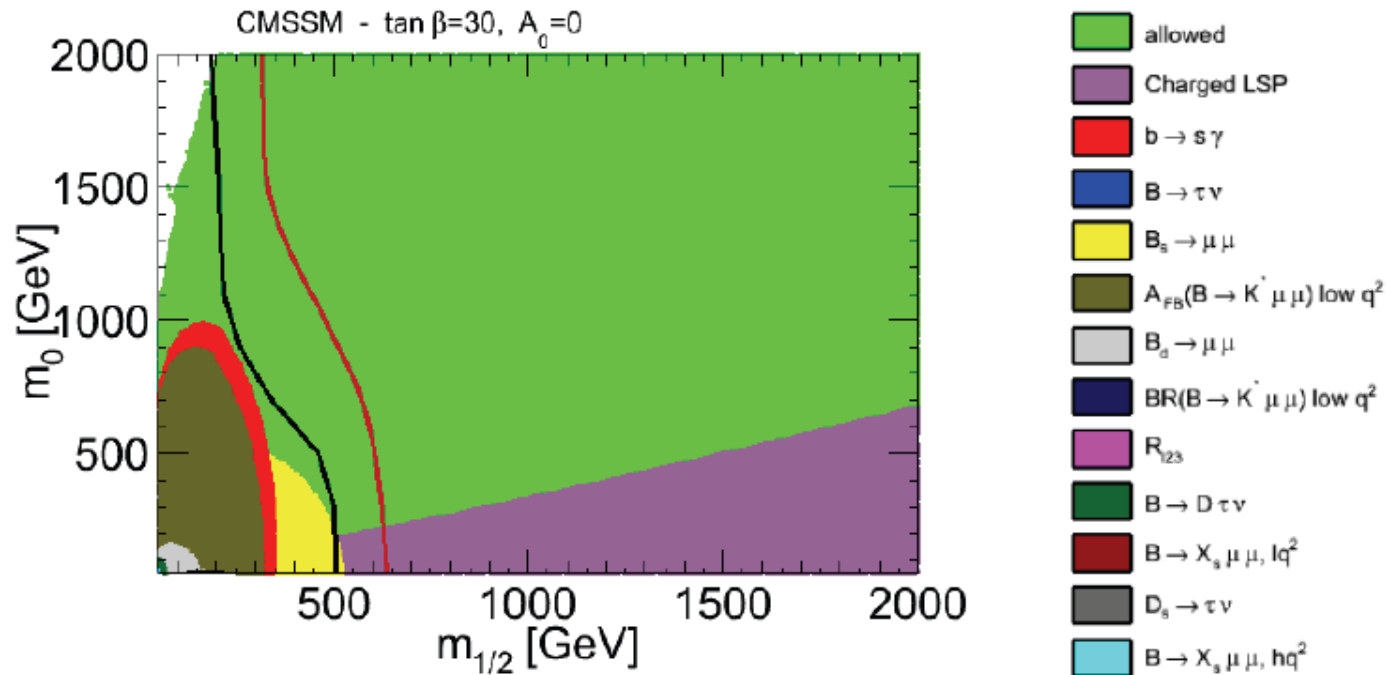
# Low Energy Searches for SUSY : GIM Violation



$$\sum_i V_{ib}^* V_{is} f\left(\frac{m_i}{v}\right)$$

Vasiliki A Mitsou

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 Parc Científic de la U.V., C/ Catedrático José Beltrán 2, E-46980 Paterna (Valencia), Spain



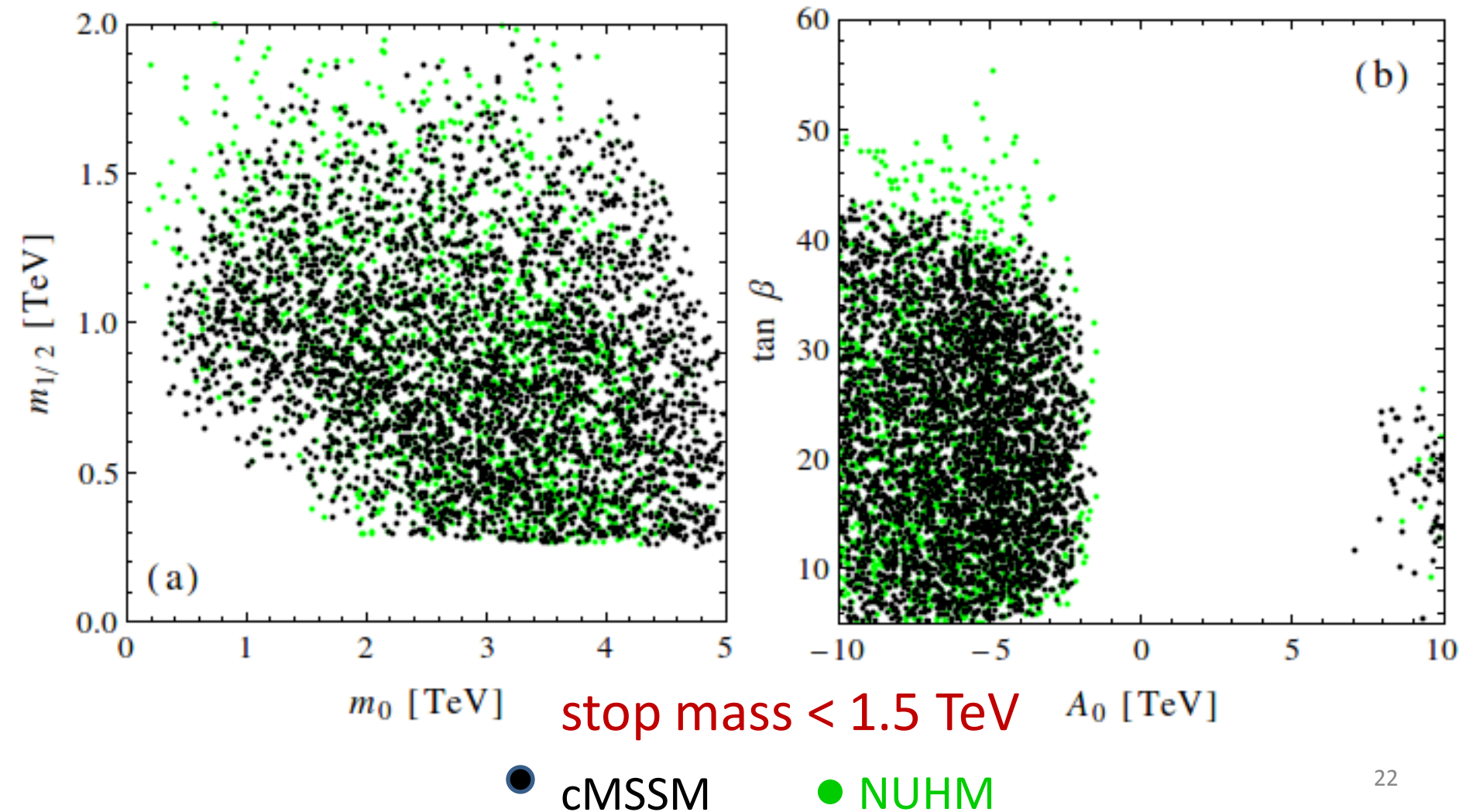
**Figure 6.** Constraints from flavour observables in CMSSM in the plane  $(m_{1/2}, m_0)$  for  $\tan \beta = 30$  and  $A_0 = 0$  with the 2011 results. The black line corresponds to the CMS exclusion limit with  $1.1 \text{ fb}^{-1}$  of data [38] and the red line to the CMS exclusion limit with  $4.4 \text{ fb}^{-1}$  of data [39]. From [37].

# Testing Times for Supersymmetry: Looking Under the Lamp Post

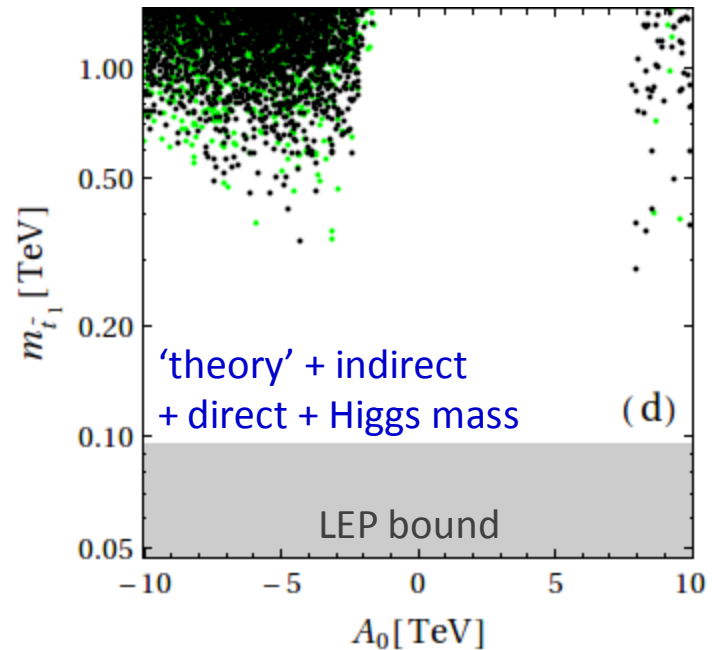
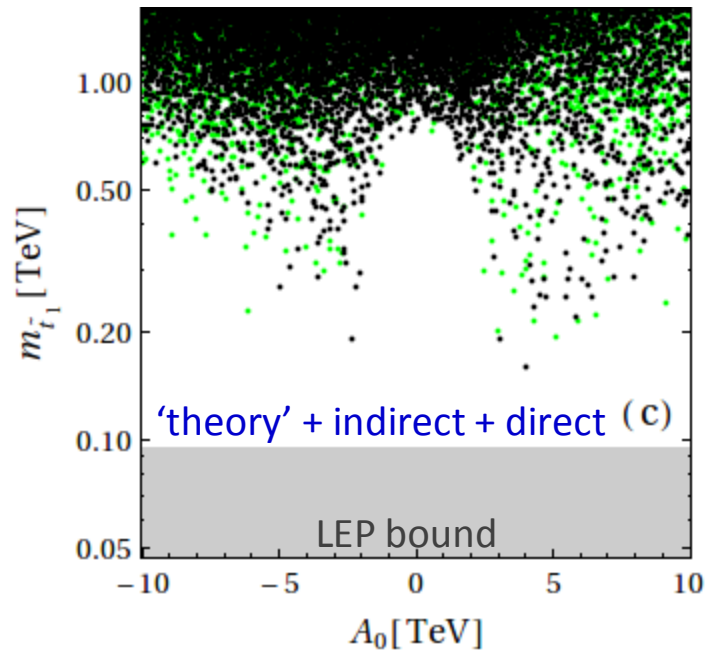
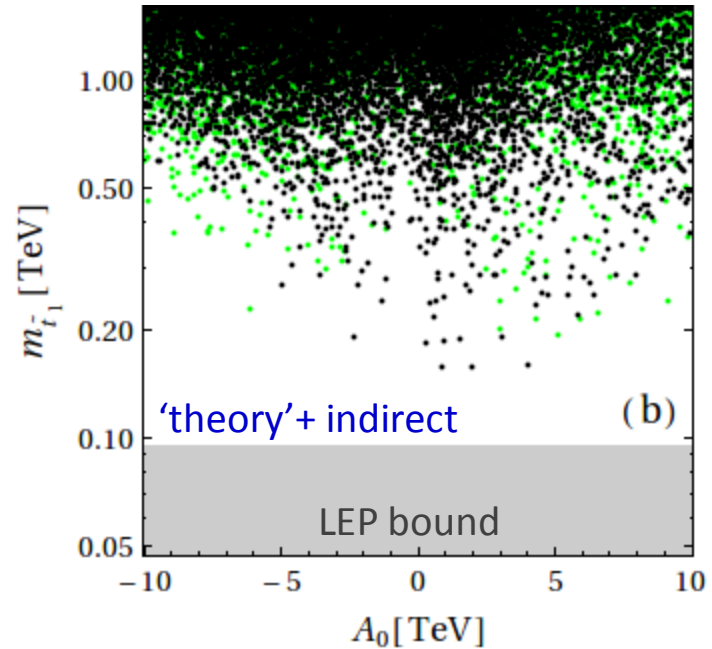
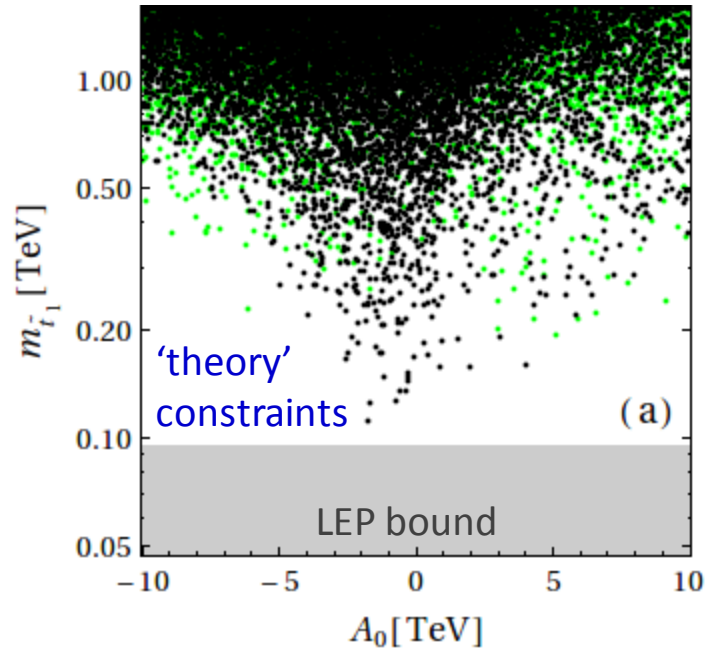
Amol Dighe,<sup>1</sup> Diptimoy Ghosh,<sup>2</sup> Ketan M. Patel,<sup>1</sup> and Sreerup Raychaudhuri<sup>1</sup>

<sup>1</sup>*Department of Theoretical Physics, Tata Institute of Fundamental Research, Mumbai 400 005, India.*

<sup>2</sup>*INFN, Sezione di Roma, Piazzale A. Moro 2, I-00185 Roma, Italy.*



# Collected constraints

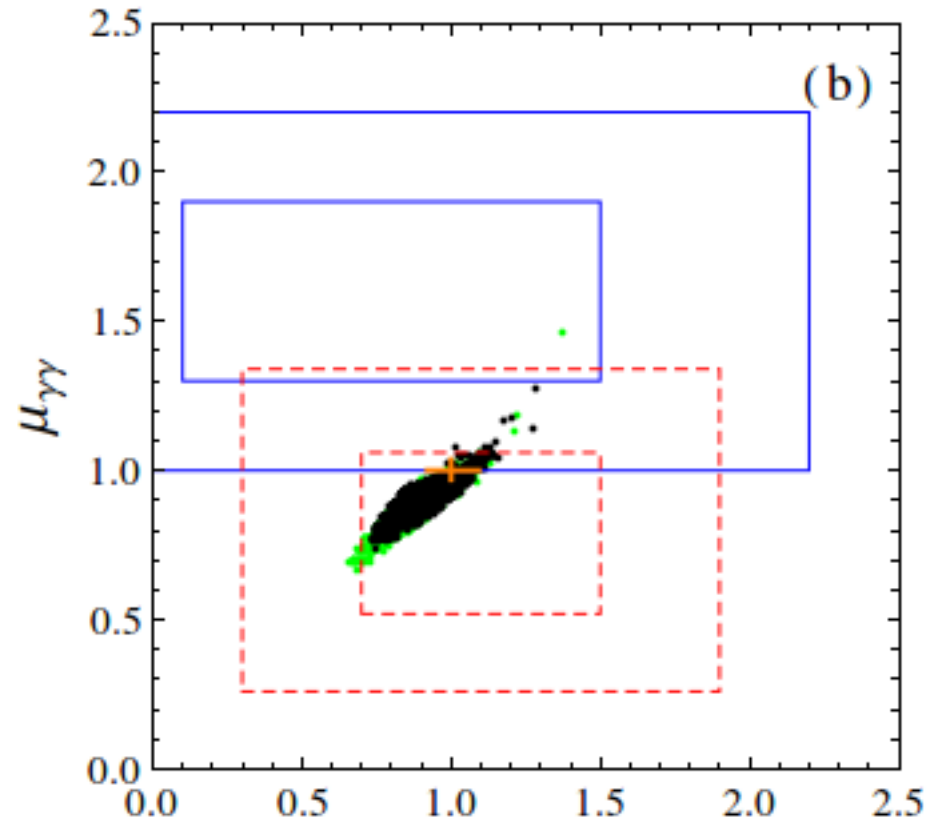
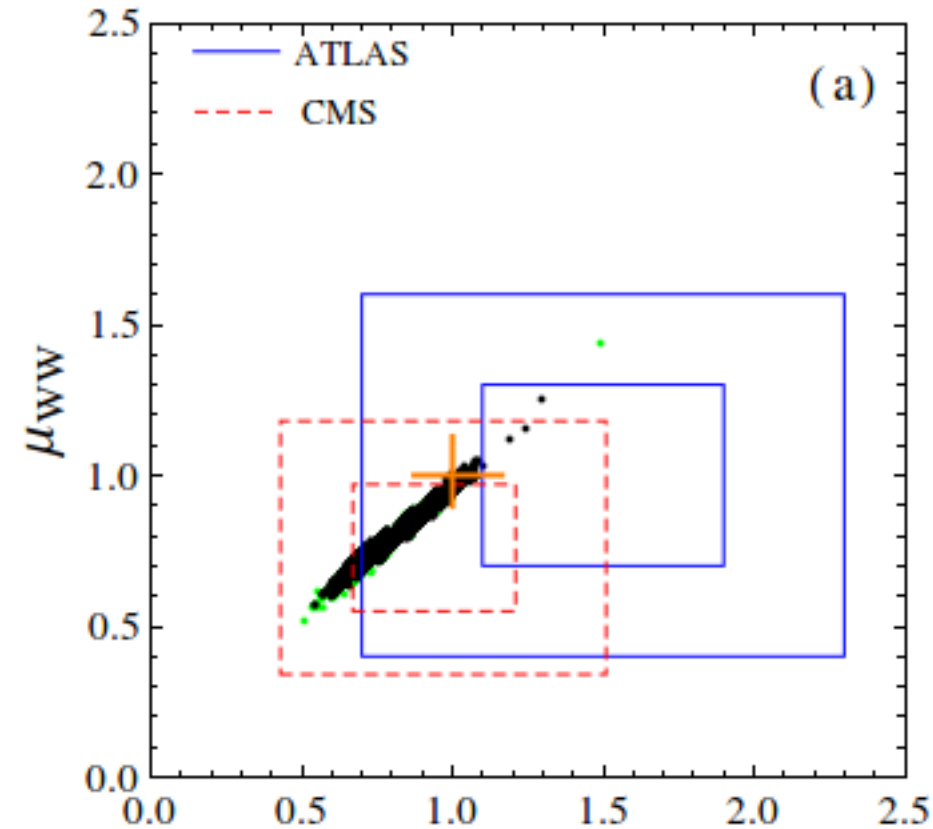


- cMSSM
- NUHM

CMS

ATLAS

## Higgs decay constraints



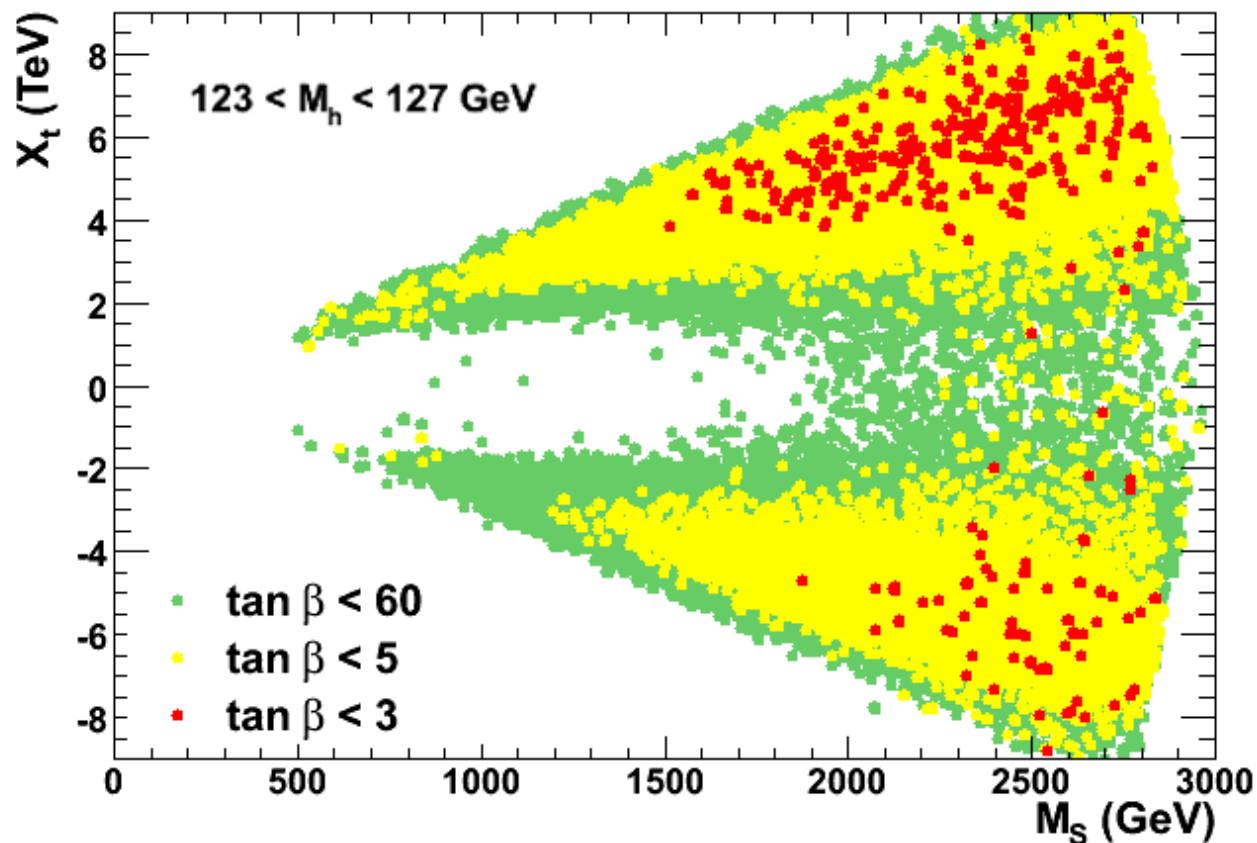
$$N_{X\bar{X}} = \mathcal{L} \times \sigma(pp \rightarrow h^0) \times \mathcal{B}(h^0 \rightarrow X\bar{X})$$

$$\mu_{X\bar{X}} \equiv \frac{N_{X\bar{X}}}{N_{X\bar{X}}^{\text{SM}}} = \frac{\sigma(pp \rightarrow h^0)}{\sigma_{\text{SM}}(pp \rightarrow h^0)} \times \frac{\mathcal{B}(h^0 \rightarrow X\bar{X})}{\mathcal{B}_{\text{SM}}(h^0 \rightarrow X\bar{X})}$$



# The pMSSM

$m_{\tilde{L}(e)_{1,2,3}}$	100 GeV – 4 TeV
$m_{\tilde{Q}(q)_{1,2}}$	400 GeV – 4 TeV
$m_{\tilde{Q}(q)_3}$	200 GeV – 4 TeV
$ M_1 $	50 GeV – 4 TeV
$ M_2 $	100 GeV – 4 TeV
$ \mu $	100 GeV – 4 TeV
$M_3$	400 GeV – 4 TeV
$ A_{t,b,\tau} $	0 GeV – 4 TeV
$M_A$	100 GeV – 4 TeV
$\tan \beta$	1 - 60
$m_{3/2}$	1 eV – 1 TeV ( $\tilde{G}$ LS)



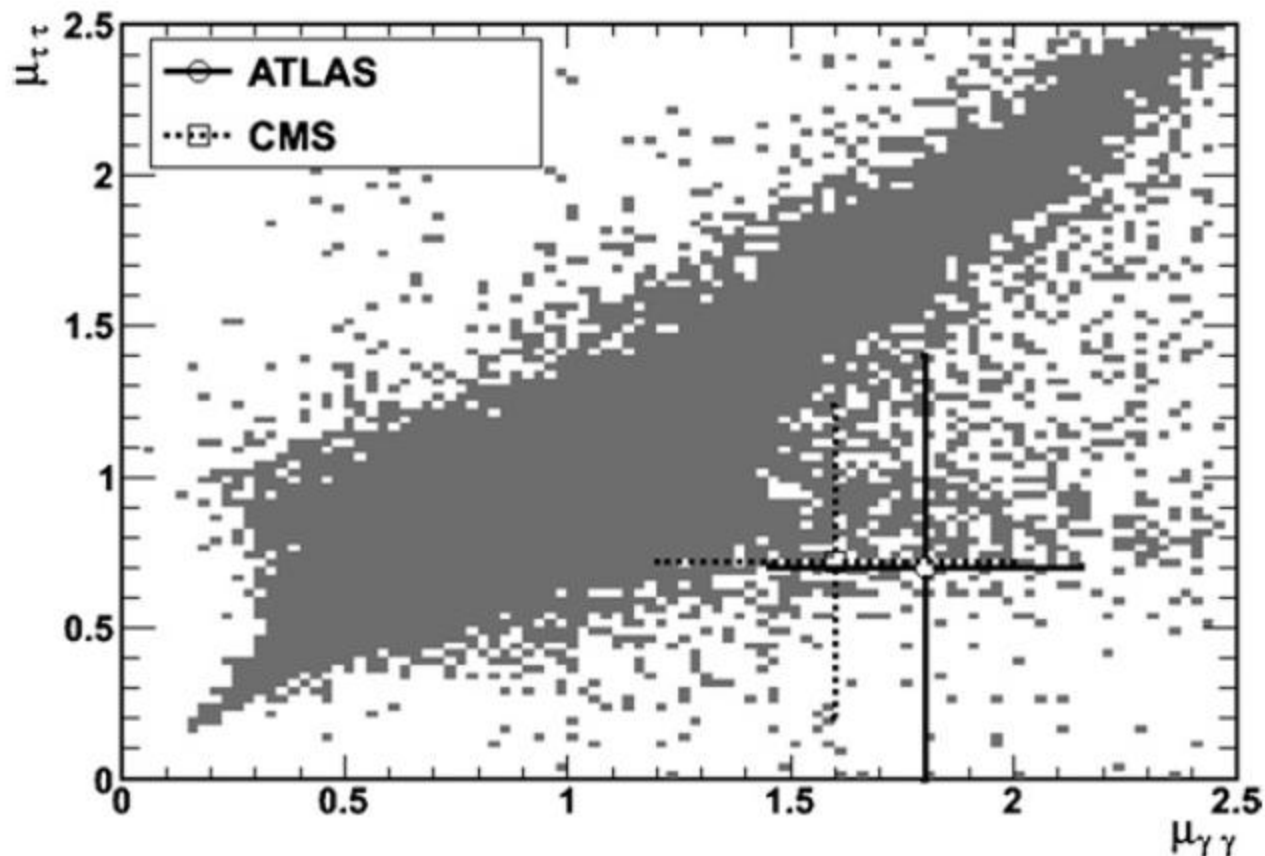
# An update of the constraints on the phenomenological MSSM from the new LHC Higgs results

Alexandre Arbey<sup>a,b,c</sup>, Marco Battaglia<sup>d,c,\*</sup>, Abdelhak Djouadi<sup>e</sup>, Farvah Mahmoudi<sup>f,c</sup>

Input values for the Higgs mass and rates used for the study.

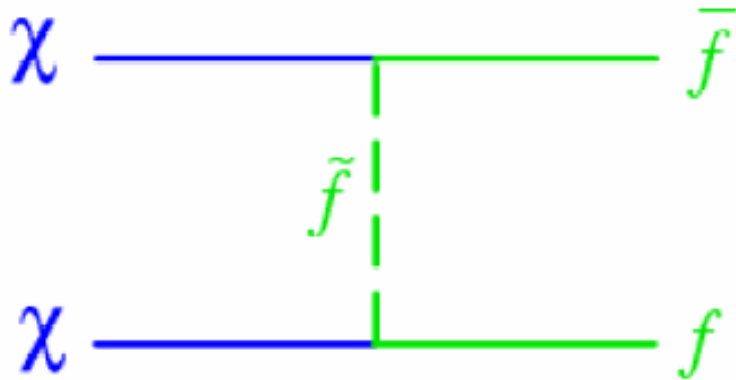
Parameter	Value	Experiment
$M_h$	$126 \pm 2$ GeV	ATLAS [1] + CMS [2]
$\mu_{\gamma\gamma}$	$1.71 \pm 0.26$	ATLAS [3] + CMS [5]
$\mu_{ZZ}$	$0.97 \pm 0.26$	ATLAS [4] + CMS [6]
$\mu_{WW}$	$0.85 \pm 0.23$	ATLAS [7] + CMS [6]
$\mu_{b\bar{b}}$	$1.28 \pm 0.45$	
$\mu_{\tau\tau}$	$0.71 \pm 0.42$	
$D_{\gamma\gamma}$	$1.88 \pm 0.46$	
$D_{\tau\tau}$	$0.79 \pm 0.49$	

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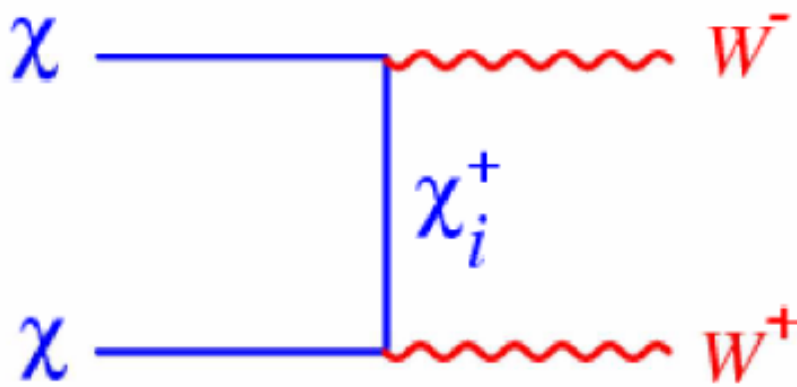


# SUSY Dark Matter

...but two main classes:



- fermion diagrams:  $m_f/M_W$  helicity suppression due to Majorana nature of neutralino

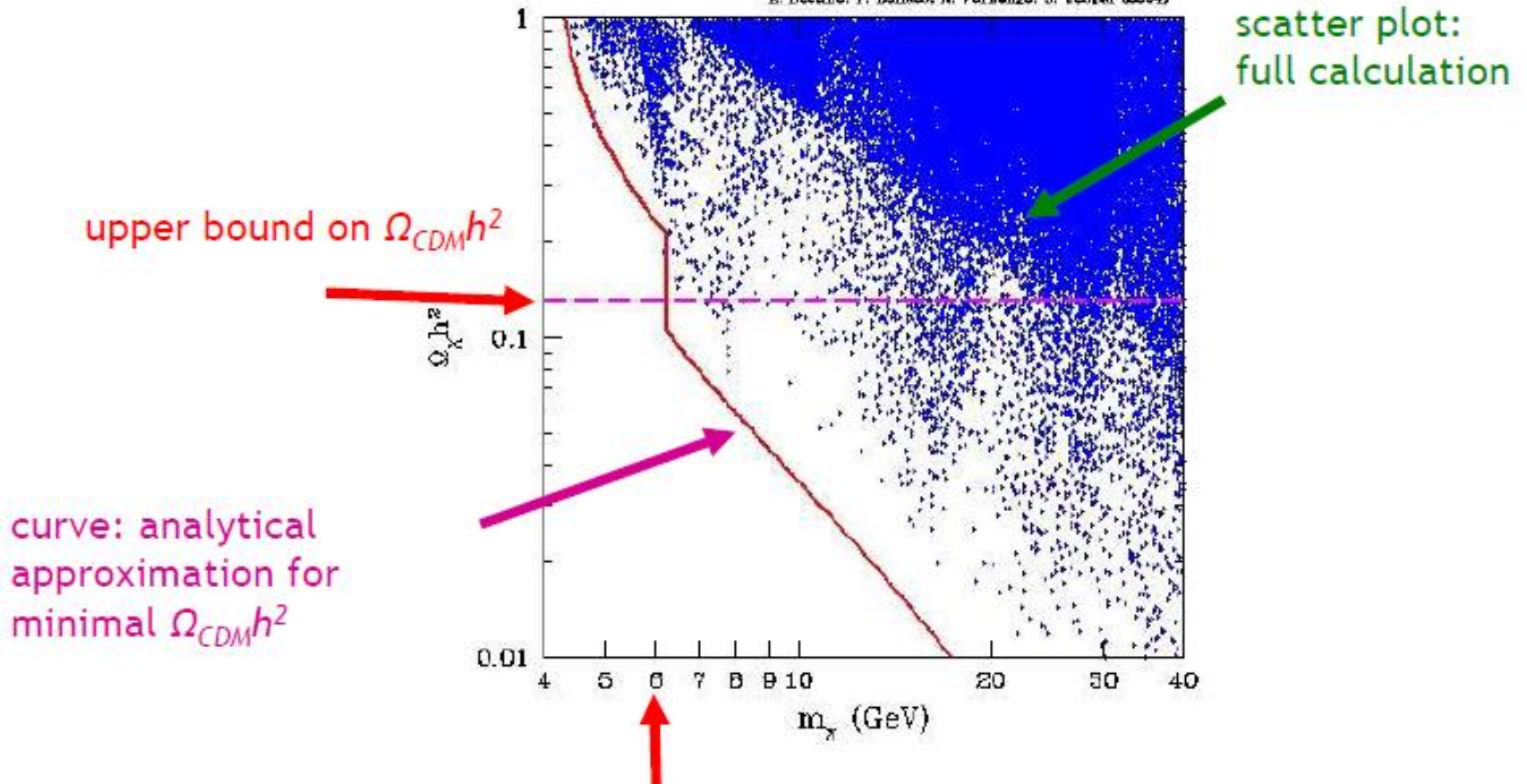


- Gauge boson diagrams: suppressed if neutralino  $\sim$  Bino (this is usually the case when Radiative ElectroWeak Symmetry Breaking is implemented,  $|\mu| \gg M_1, M_2$ )

# Cosmological lower bound on $m_\chi$

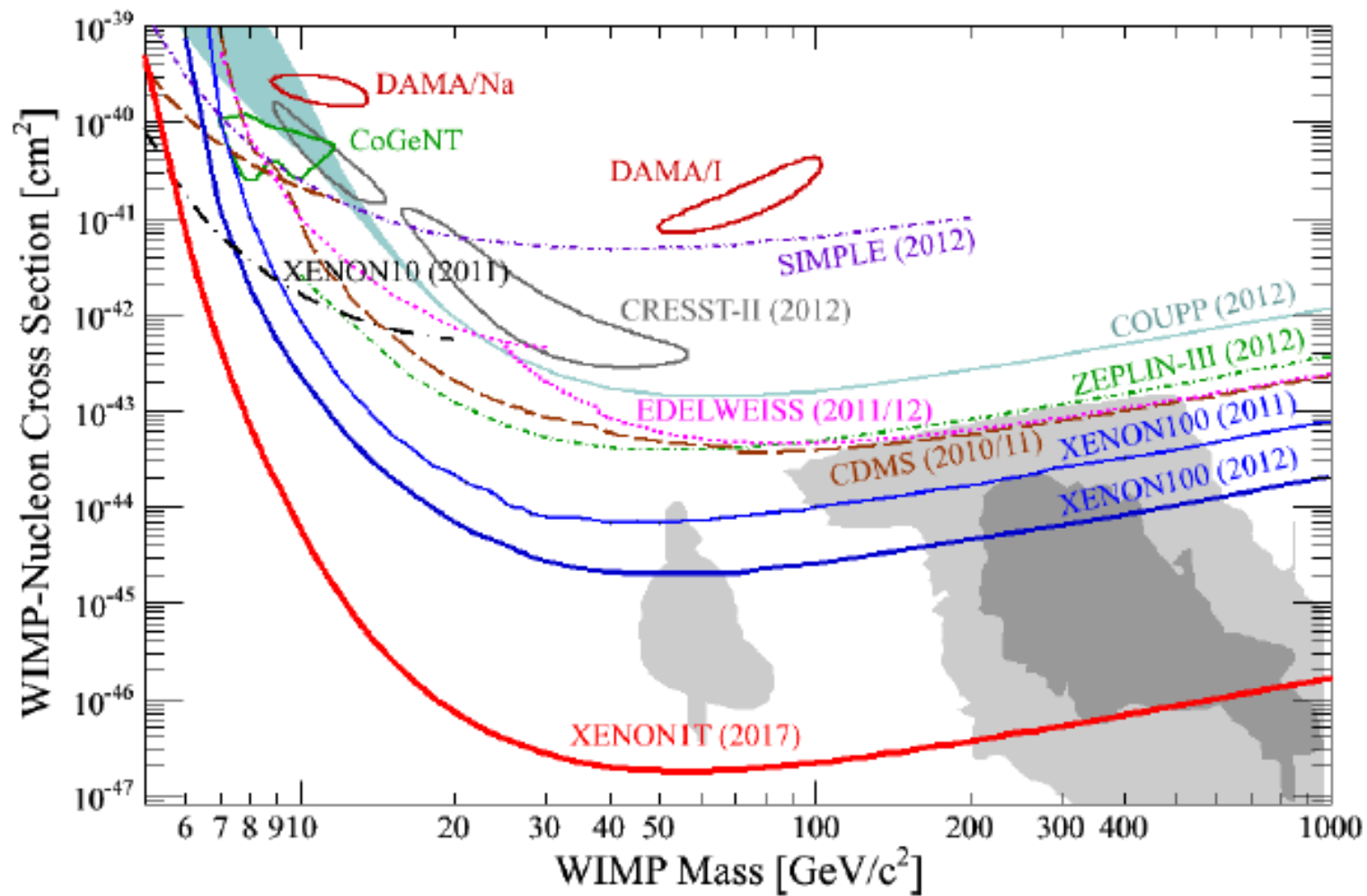
A. Bottino, F. Donato, N. Fornengo, S. Scopel, Phys. Rev. D 68, 043506 (2003)

A. Bottino, F. Donato, N. Fornengo, S. Scopel (2004)



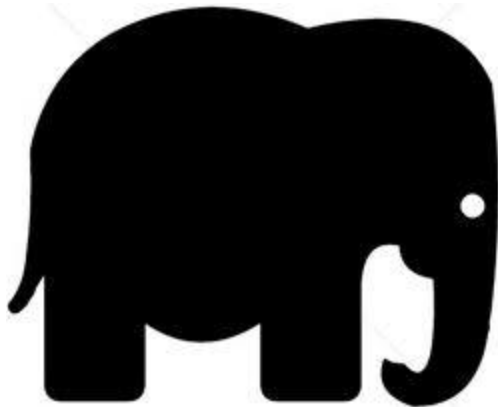
$$m_\chi [1 - m_b^2/m_\chi^2]^{1/4} \gtrsim 5.3 \text{ GeV} \left(\frac{m_A}{90 \text{ GeV}}\right)^2$$

# Direct Search:



# Conclusions

- Electroweak-scale SUSY remains the best BSM option
- It was not just around the corner when LHC started
- B factories have also come up with a blank
- No reason to despair yet (recall wait for the Higgs)
- We may have to live with some minor fine-tuning



**Thank You**