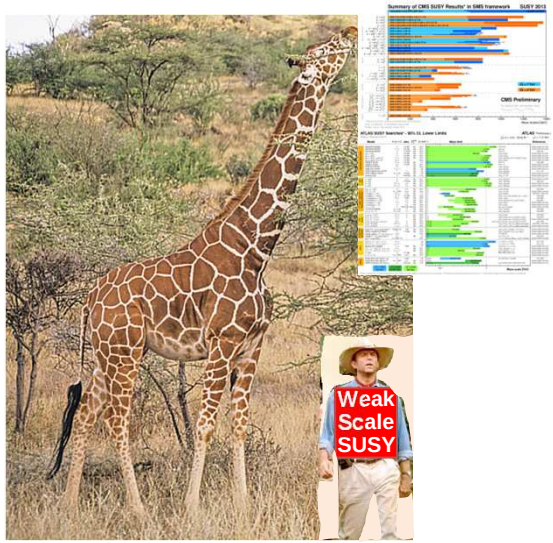
SUSY searches : lessons from LHC run 1*

Pascal Pralavorio **(pralavor@cppm.in2p3.fr)**

CPPM/IN2P3–Univ. de la Méditerranée (Marseille, FRANCE)

Blois 2014 (20 May 2014)



``I am sure we all agree that a giraffe is truly beautiful,
but she doesn't seem to serve any purpose"
J. Weiss (1974)

* See 1404.7191 for a full review

General Framework (1)

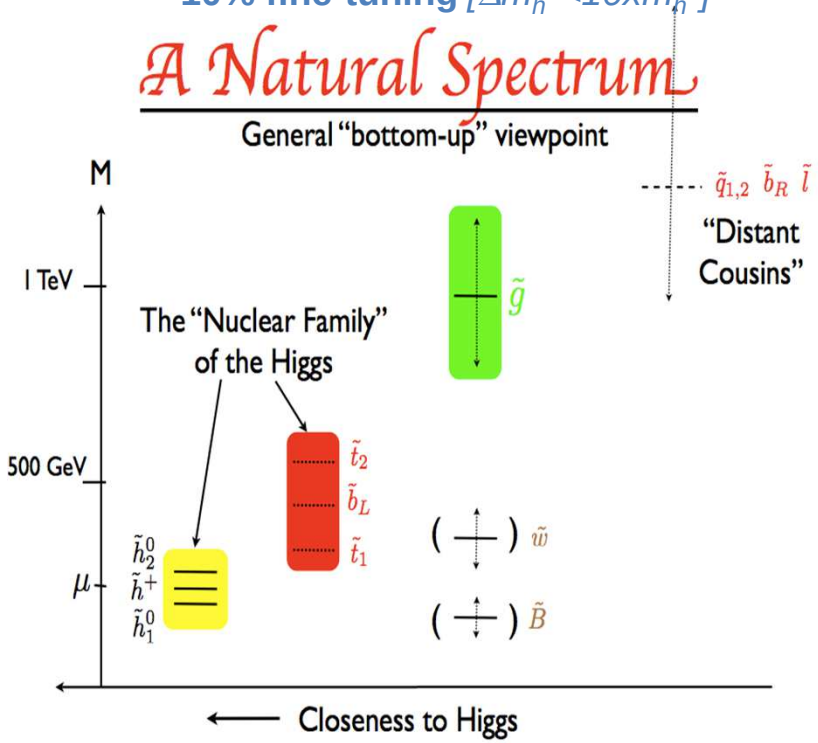
- **Particle physics is truly beautiful, SUSY serves a natural purpose...**
  - … and predict a mass spectrum of new particles accessible at LHC !

Minimal Supersymetric Standard Model (MSSM) : 29 sparticles + 4 Higgs undiscovered *[h^0=H(125)]*

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$h_1^0\ h_2^0\ h_1^+\ h_2^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	(same) (same) $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	(same) (same) $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{h}_1^0\ \tilde{h}_2^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{h}^+\ \tilde{h}^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

S. Martin, SUSY Primer, hep-ph/9709356

MSSM, aka weak scale SUSY for less than 10% fine-tuning *[$\Delta m_h^2 < 10 \times m_h^2$]*



L. Hall, BNL SUSY Workshop, Oct 2011

No limit on this spectrum before LHC start !!!

General Framework (2)

- **Need three more assumptions before we start**

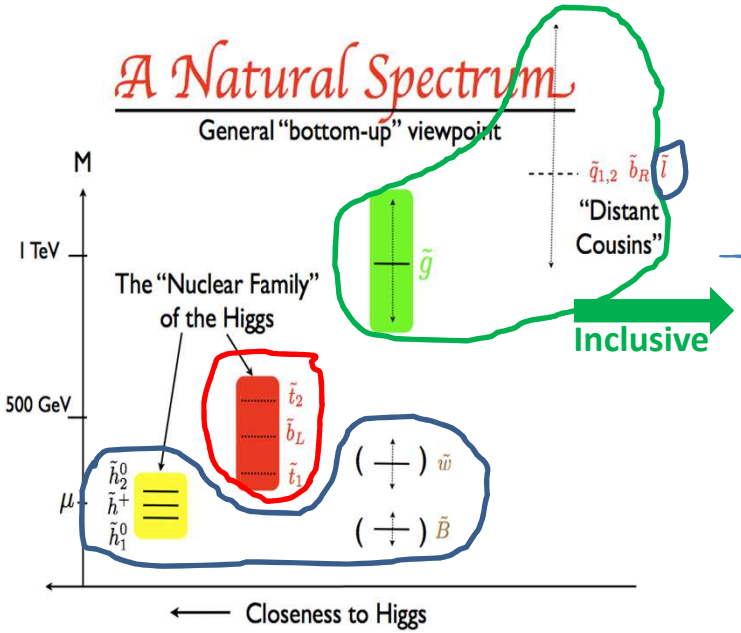
1. R-Parity (P_R=*-1 for SUSY particles / +1 for SM particles*) is conserved
   - SUSY particles are pair-produced at LHC and the lightest one is stable
   - R-parity violation or discrete symmetry also possible (see end of the talk)

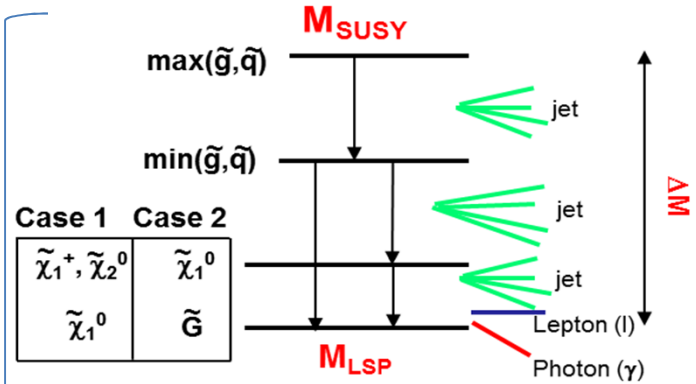
2. The nature of the stable Lightest SUSY particle (LSP) in the MSSM:
   - case 1: $\tilde{\chi}_1^0$ with M_{LSP} > GeV or case 2: $\tilde{G}$ with M_{LSP} << GeV

3. The value of $\Delta M = M_{SUSY}$[highest particle produced at LHC] - M_{LSP}
   - **Assume generally ΔM > O(100) GeV → open spectra → high energetic objects**
   - If ΔM < O(100) GeV → compressed spectra → very difficult experimentally

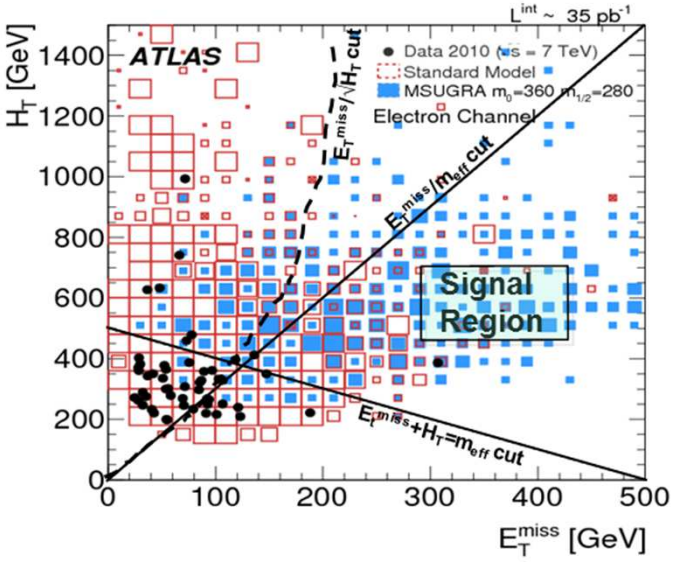
These 3 assumptions + naturalness = **"plain vanilla"** Weak scale SUSY
That we can discover (or exclude) at the LHC

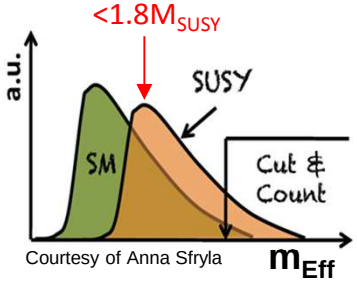
SUSY at LHC : strategy (1)





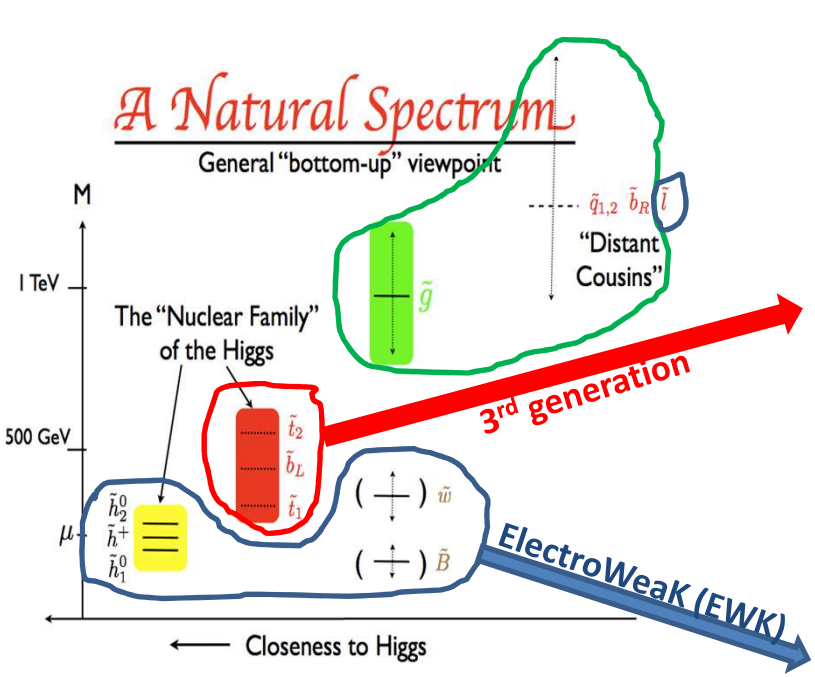
- Absolute value of vectorial sum: $E_T^{miss} \sim \Delta M$
- Scalar sum: $H_T = \Sigma\ p_T(jet)\ [+\ p_T(l,\gamma)] \sim \Delta M$
- $m_{eff} = E_T^{miss} + H_T \sim 1.8(M_{SUSY}^2 - M_{LSP}^2)/M_{SUSY}$ [hep-ph/0006276]

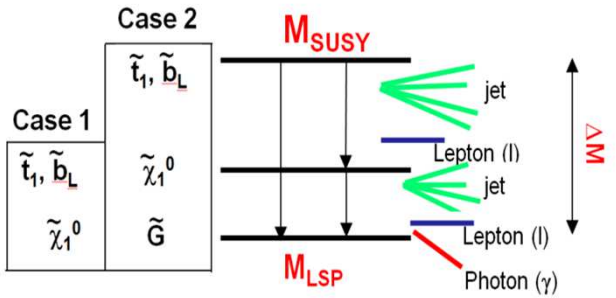




Multijets
+ E_T^{miss}
+ **0**/1/2 lepton
+ 0/1/2 photon

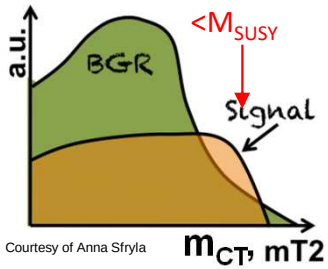
SUSY at LHC : strategy (2)

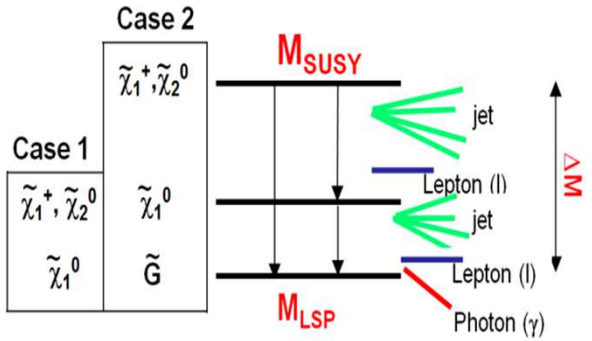




• Absolute value of vectorial sum: $E_T^{miss} \sim \Delta M$
• Number of b-jets
• Endpoint at $m_{CT} \sim (M_{SUSY}^2 - M_{LSP}^2)/M_{SUSY}$ [0802.2879,0910.0174]

Multi b-jets
+ E_T^{miss}
+ 0/**1**/2 lepton
+ 0/1/2 photon



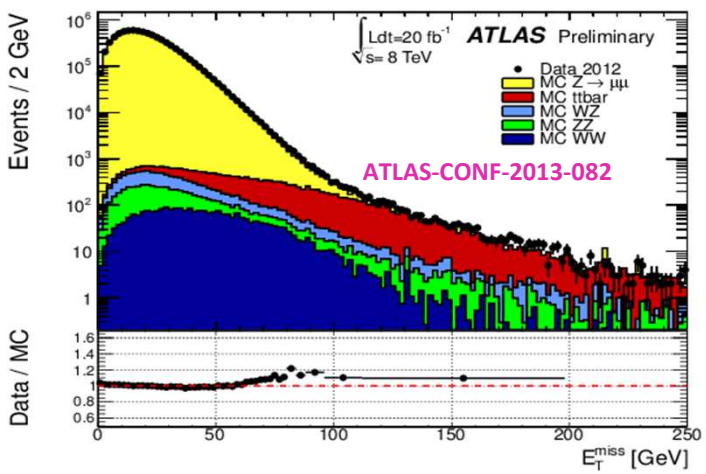


• Absolute value of vectorial sum: $E_T^{miss} \sim \Delta M$
• Number of jets (can be jet-veto !)
• Endpoint at $m_{T2} \sim (M_{SUSY}^2 - M_{LSP}^2)/M_{SUSY}$ [hep-ph/9906349,0304226]

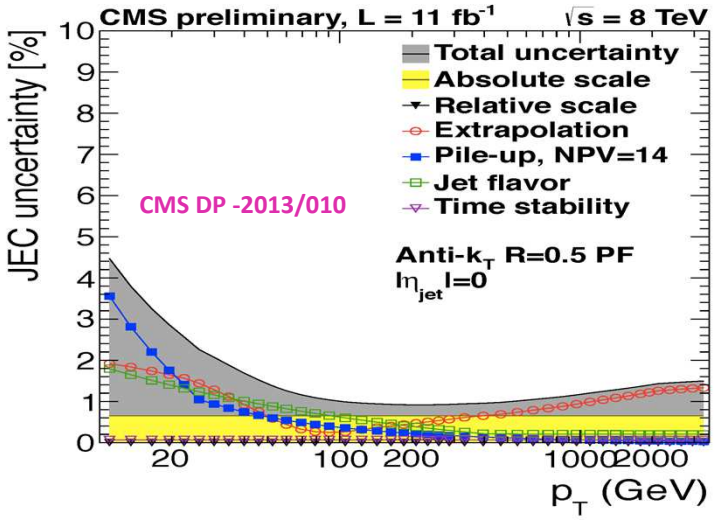
0/1/2 jets
+ E_T^{miss}
+ 1/**2**/**3**/4 lepton
+ 0/1/2 photon

SUSY at LHC : ingredients

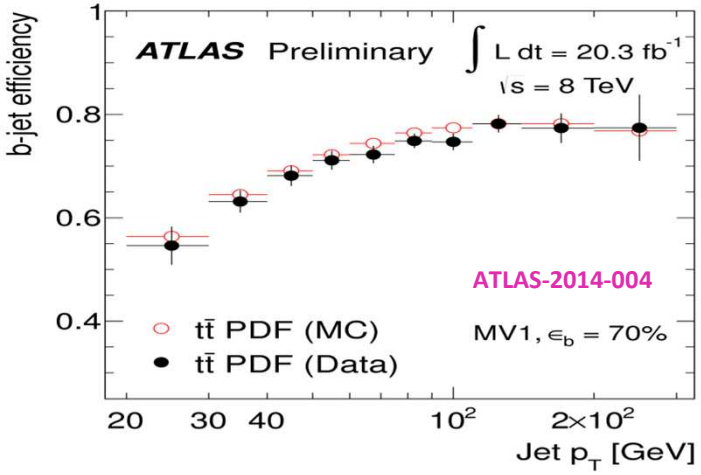
E_T^{miss} Tail (and shape) under control



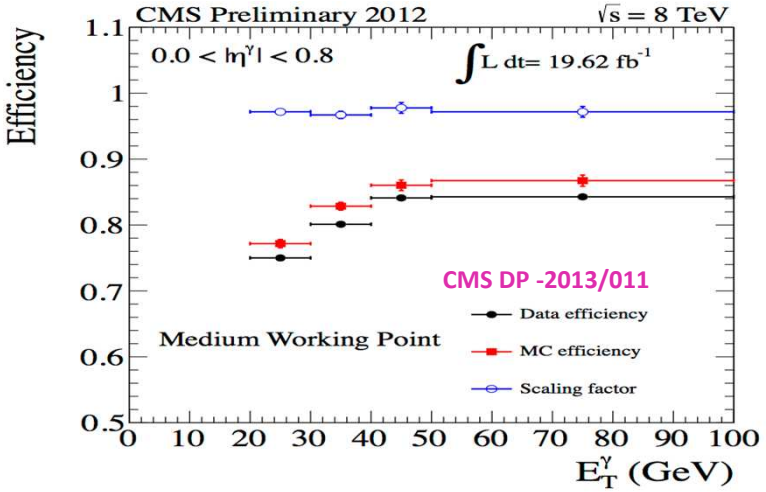
Jet energy scale under control



B-tagging understood

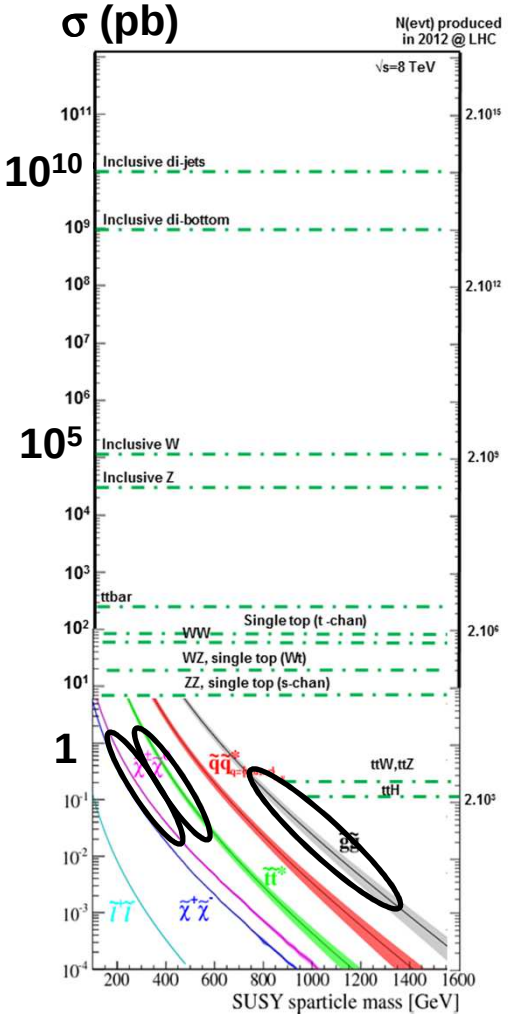


Photon understood

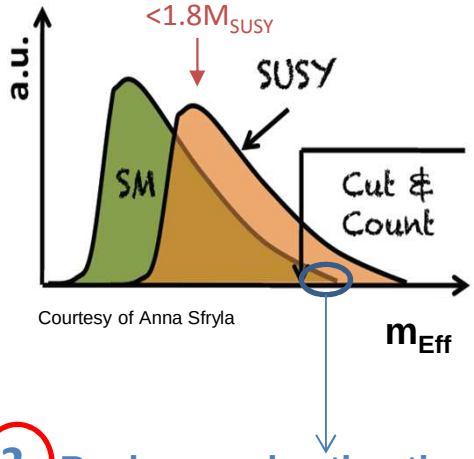


SUSY at LHC : keys of the success

Very low σ~1fb - 1pb



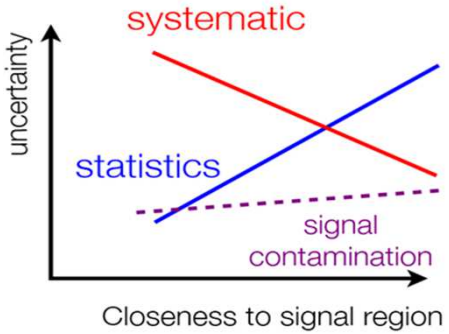
1 Powerful discriminants



2 Background estimation

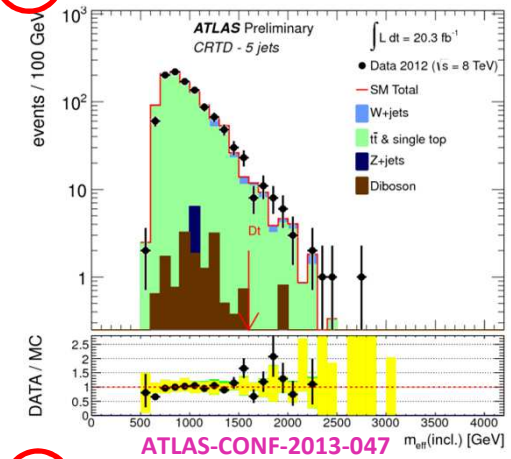
1- Multijets: jet smearing method

2- W, Z, t, VV : control regions



3- ttV: Monte Carlo

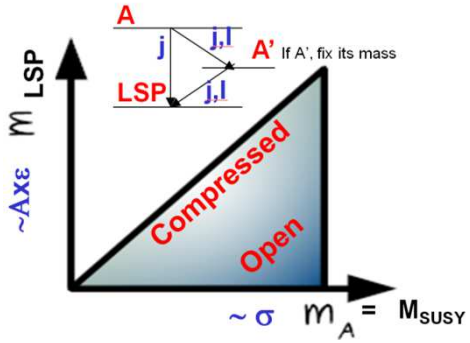
3 Well understood Monte Carlos



4 Interpretation if no excess

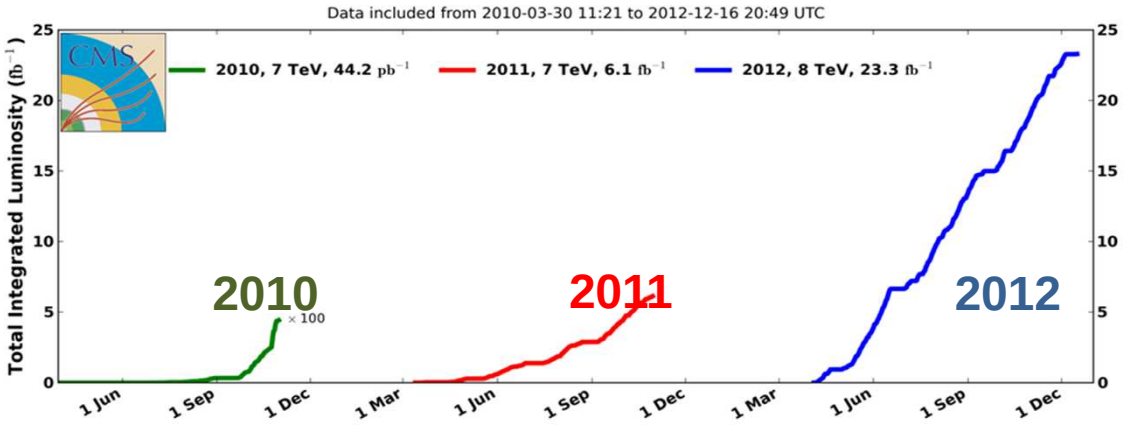
1- Constraint model, e.g. MSUGRA

2- Simplified/topological models

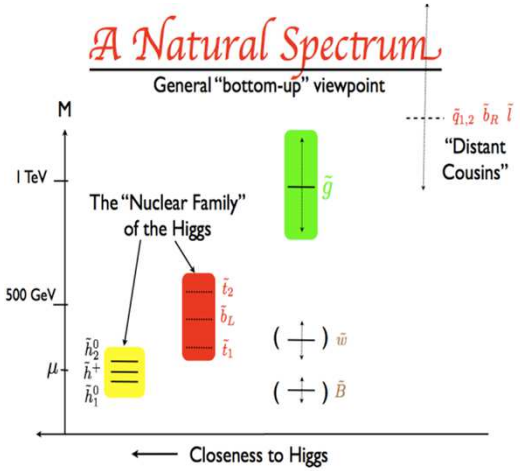


3- Phenomenological models, eg. pMSSM

SUSY at LHC : results !



e.g. ATLAS (CMS similar)



Npapers (+ NCONF)	2010--0.04fb^{-1}	2011–1,2,5 fb^{-1}	2012–20 fb^{-1}	TOT
Gluinos (1/2nd gene. squarks)	6	16	2 (+6)	**24**
Stops, sbottom	0	7	3 (+6)	**16**
EWKinos (sleptons)	0	4	2 (+4)	**10**
RPV, Long-Lived Particles, Beyond MSSM, …	6	13	2 (+5)	**26**
Total	12	40	9 (23)	**82**
Citations (Inspire 15/04/2014)	~900	~2250	~100 (650)	**~3900**

Note: ATLAS Higgs discovery paper: 2500 citations

A huge effort from ATLAS and CMS to find SUSY !

Report only on a selection of full 2012 results …

EWK SUSY

See more in F. Legger's talk

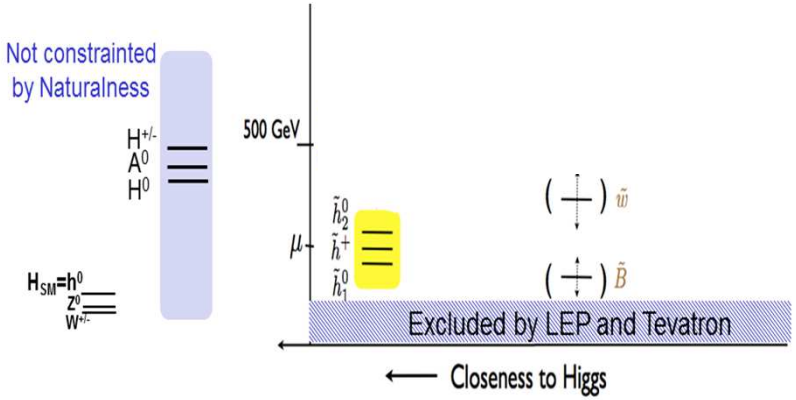
❑ Closer look at EWK SUSY

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	h_1^0, h_2^0, h_1^+, h_2^-	h^0 H^0 A^0 $H^\pm$
neutralinos	1/2	−1	$\widetilde{B}^0$ $\widetilde{W}^0$ $\widetilde{h}_1^0$, $\widetilde{h}_2^0$	$\widetilde{N}_1$ $\widetilde{N}_2$ $\widetilde{N}_3$ $\widetilde{N}_4$
charginos	1/2	−1	$\widetilde{W}^\pm$ $\widetilde{h}^+$, $\widetilde{h}^-$	$\widetilde{C}_1^\pm$ $\widetilde{C}_2^\pm$

Governed by M_1, M_2, μ ($\tan\beta$, m_A)

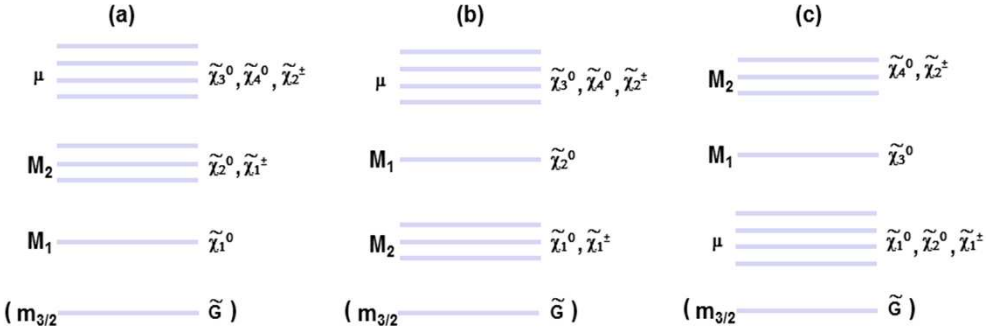
Bino Wino Higgsino

Higgs Bosons (See S. Dawson)



❑ Hypotheses for the result presentation

- Consider the 3 "extreme" cases
- H^0, A^0, $H^{+/-}$, $\tilde{q}$, $\tilde{g}$, $\tilde{l}$ decoupled (pessimistic)



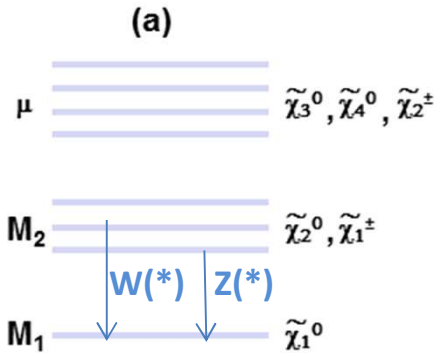
❑ Production considered at LHC

- Highest cross-section O(1)pb : $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_2^0\tilde{\chi}_1^{+/-}$ ($\tilde{\chi}_1^{+/-}\tilde{\chi}_1^0$)
- Dominant background : WW, WZ (inc. W)
- Unsensitive to $\tilde{\chi}_1^0\tilde{\chi}_1^0$ production at LHC when LSP=$\tilde{\chi}_1^0$

See more in I. Vivarelli's talk

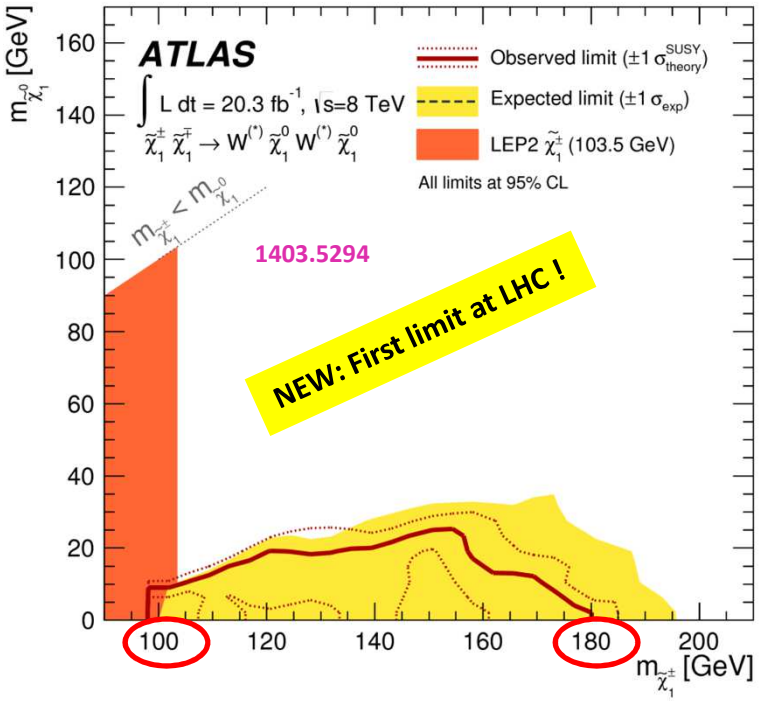
Note: these searches also address sleptons (see back-up for more details)

EWK SUSY (1)

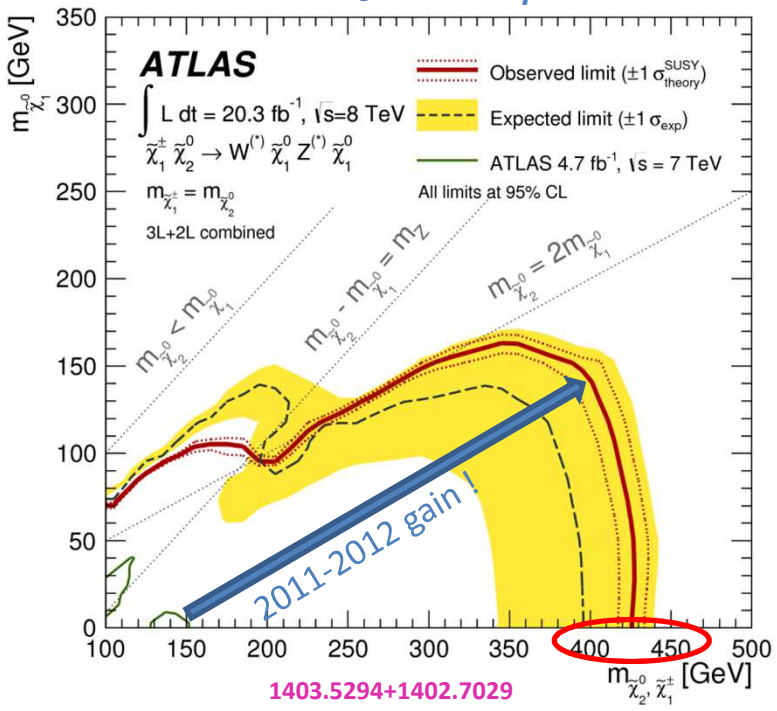


- **With $\tilde{\chi}_1^0$=LSP, consider only scenario (a)**
  - All decaying via on-shell W or Z
  - At LHC generally consider leptonic decay of W and Z

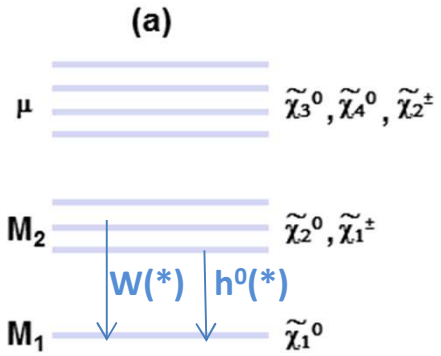
2l + E_T^{miss} + 0 jets



2l2j/3l + E_T^{mis}

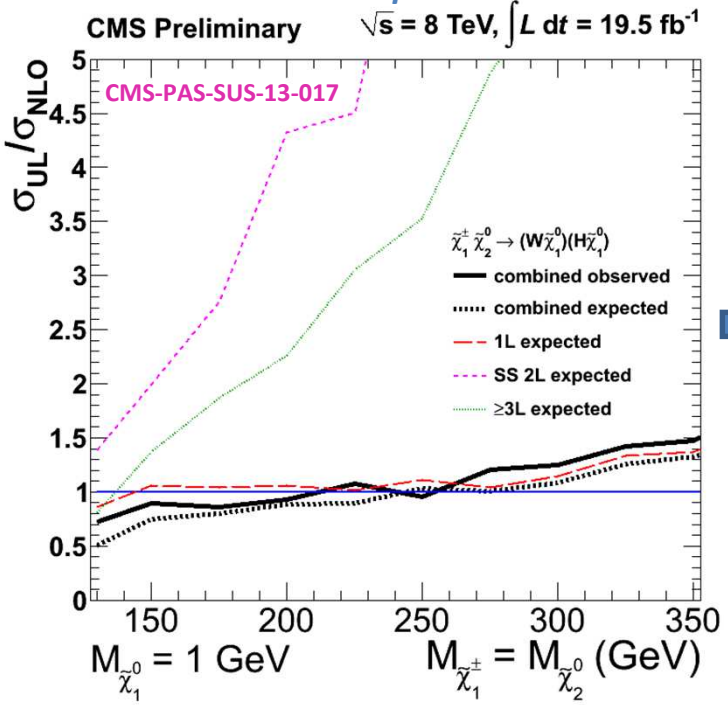


EWK SUSY (2)

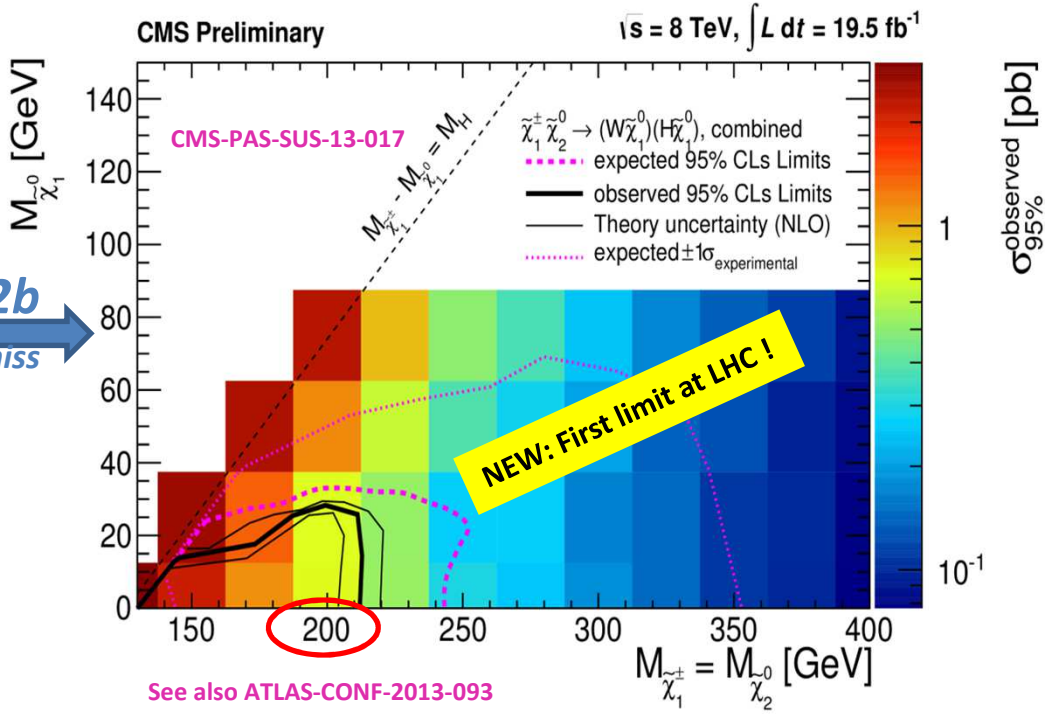


- **With $\tilde{\chi}_1^0$=LSP, consider only scenario (a)**
  - Try also with Higgs in place of Z in $\tilde{\chi}_2^0$ decay *(e.g if $M_2 \approx \mu$)*
  - Combine several Higgs decays (bb, WW, ZZ *[$\gamma\gamma$, $\tau\tau$]*)

1-4l + E_T^{miss}

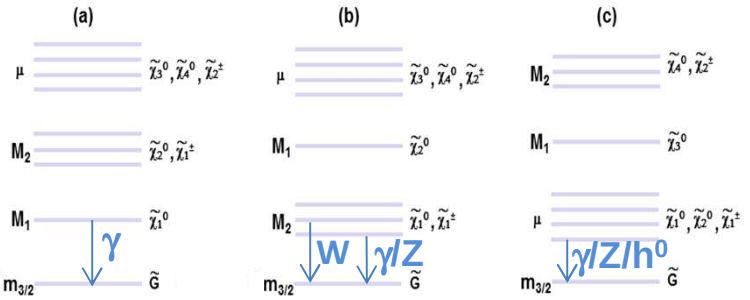


1l + 2b + E_T^{miss}



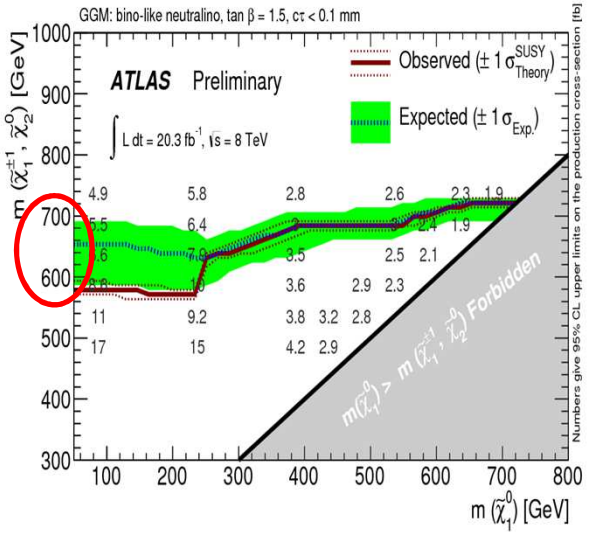
See also ATLAS-CONF-2013-093

EWK SUSY (3)



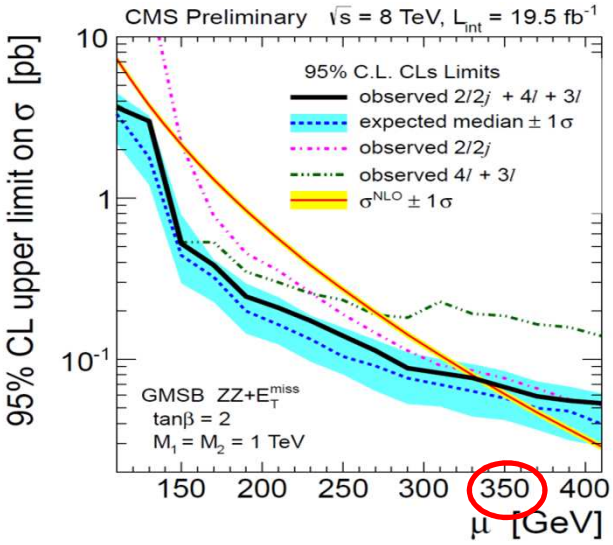
- **With $\tilde{G}$=LSP, driven by $\tilde{\chi}_1^0$ decay to $\tilde{G}$**
  - Scenario (a) gives 2 additional γ → ~no background !
  - Scenario (b) gives 1 extra W and 1 Z/γ → ~no dedicated results yet @ 8 TeV [ATLAS-CONF-2012-144]
  - Scenario (c) gives 2 extra γ/Z/h^0 depending on ΔM and tanβ

(a): $\gamma\gamma + E_T^{miss}$



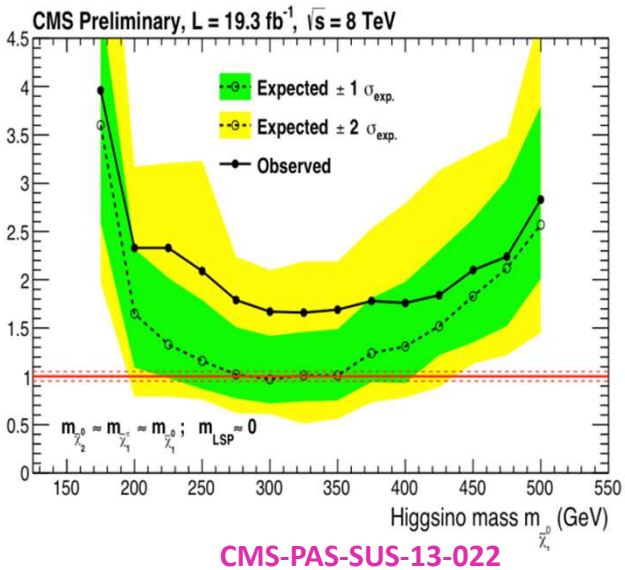
ATLAS-CONF-2014-001

(c): $ZZ(\rightarrow 2l2j,4l) + E_T^{miss}$



CMS-PAS-SUS-13-006

(c): $h^0h^0(\rightarrow 4b) + E_T^{miss}$

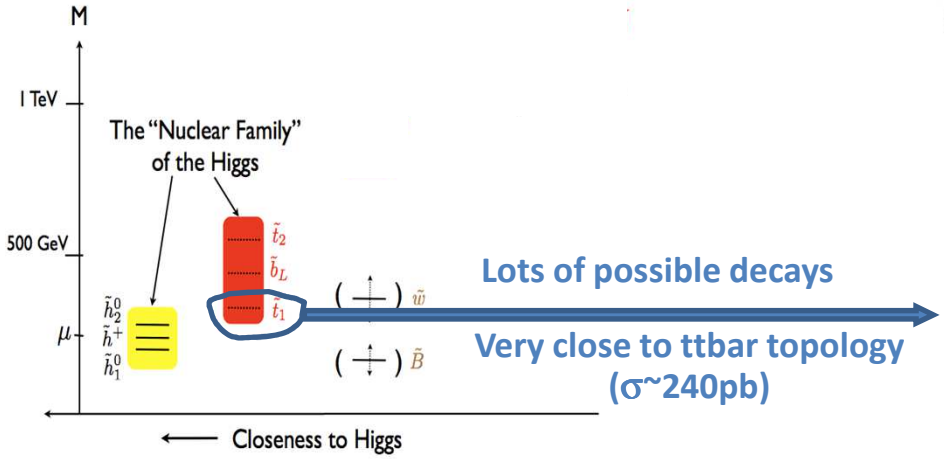


CMS-PAS-SUS-13-022

No limit yet !

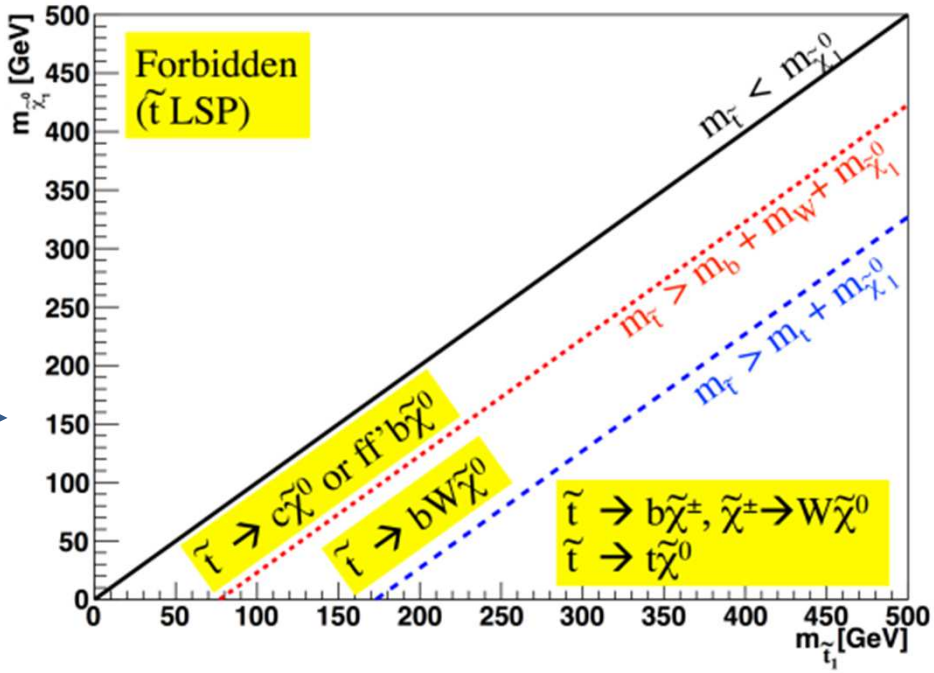
3rd generation squarks : $\tilde{t}$

See more in J. Linacre's talk



Lots of possible decays

Very close to ttbar topology (σ~240pb)



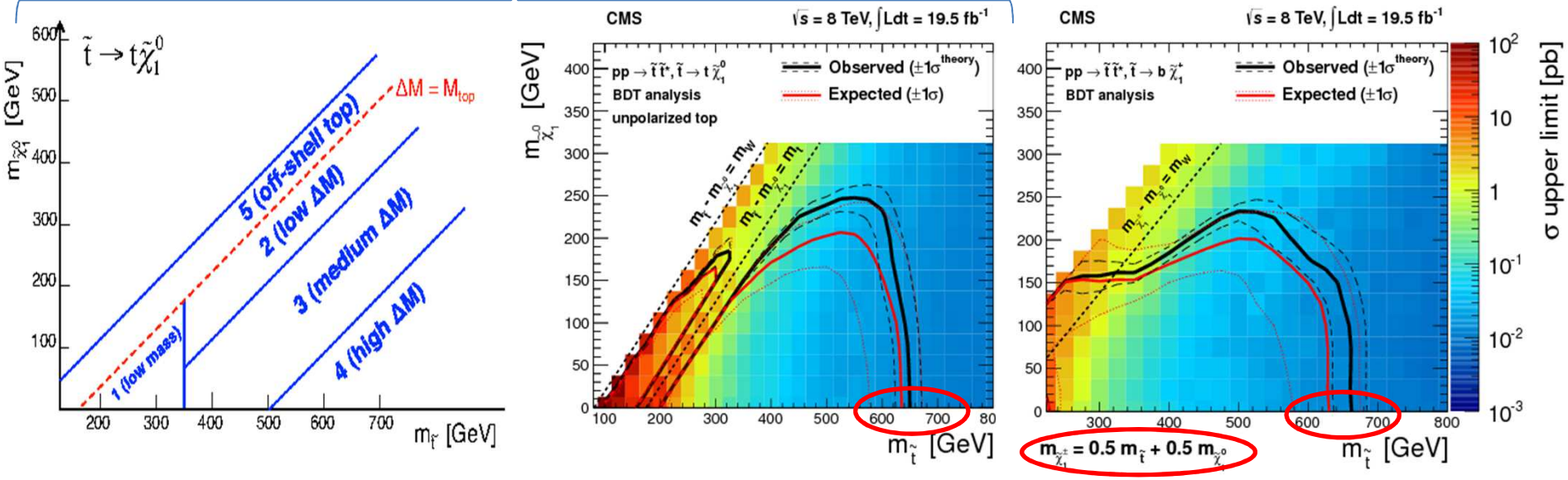
Before LHC no constraints on stop !!

3rd generation squarks : $\tilde{t}$ (1)

- **Most powerful analysis: 1l + 4j + ≥1b-jet + E_T^{miss} final state**
  - Design very carefully Signal Region (discriminant var.+ phase space regions)
  - Can look at two scenarios

100% $\tilde{t}$ ->$t\tilde{\chi}_1^0$

100% $\tilde{t}$ ->$b\tilde{\chi}_1^+$ ->$bW\tilde{\chi}_1^0$



1308.1586

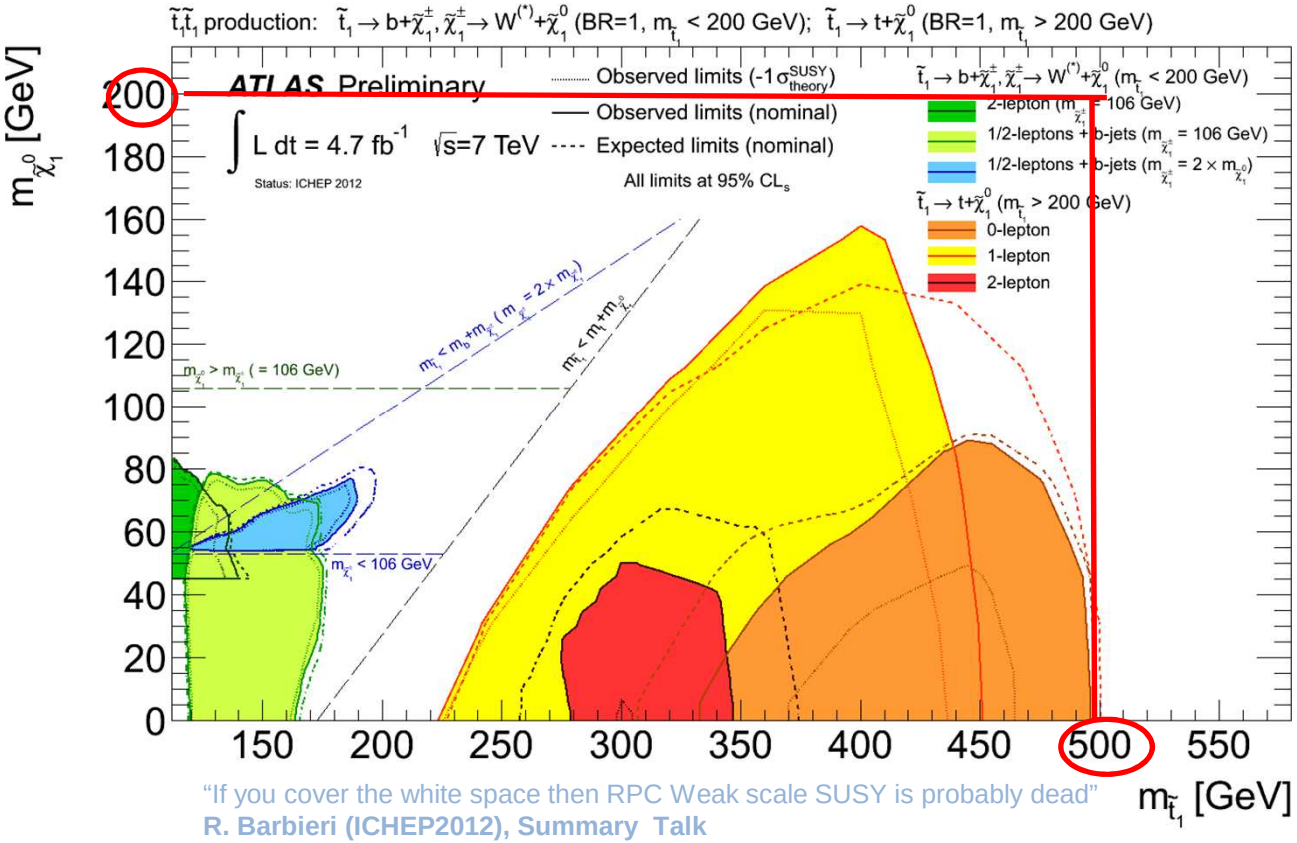
Seriously bites in the naturalness area for open spectra !

3rd generation squarks : $\tilde{t}$ (2)

❑ **Situation in July 2012 at ICHEP – at the time of the Higgs discovery**

FIRST LIMITS (July2012) ! $\sqrt{s}$=7 TeV, L=5fb^{-1}

M(LSP)= 200 GeV

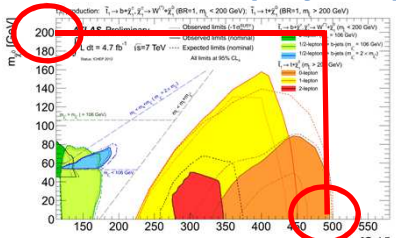


"If you cover the white space then RPC Weak scale SUSY is probably dead"
R. Barbieri (ICHEP2012), Summary Talk

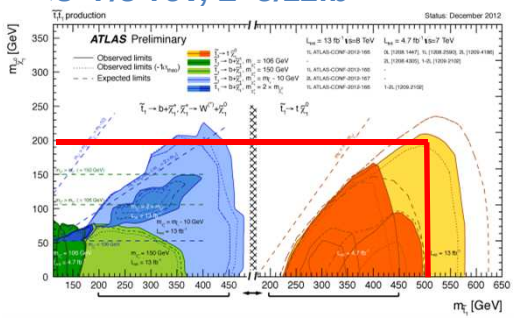
3rd generation squarks : $\tilde{t}$ (2)

- **Many other analyses and a lot of progress since ICHEP 2012**

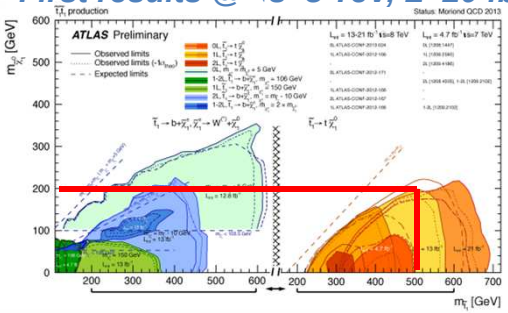
FIRST LIMITS (July2012) ! √s=7 TeV, L=5fb^{-1}



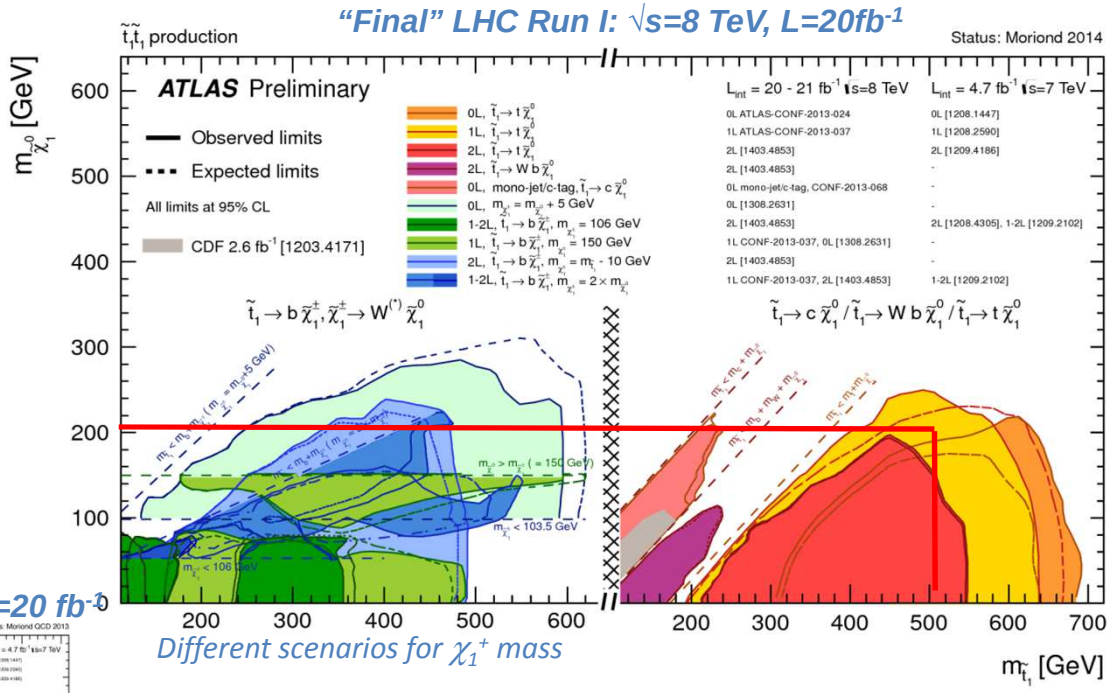
√s=7/8 TeV, L=5/12fb^{-1}



First results @ √s=8 TeV, L=20 fb^{-1}



"Final" LHC Run I: √s=8 TeV, L=20fb^{-1}

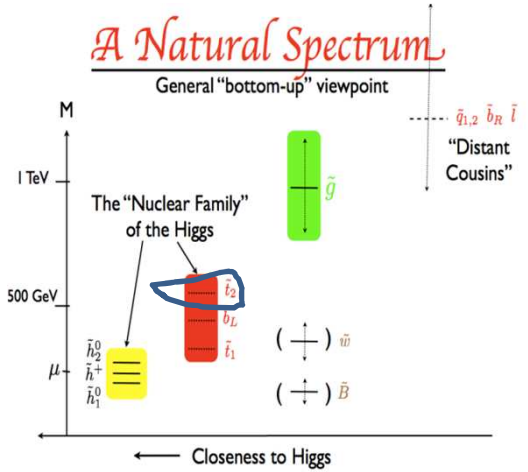


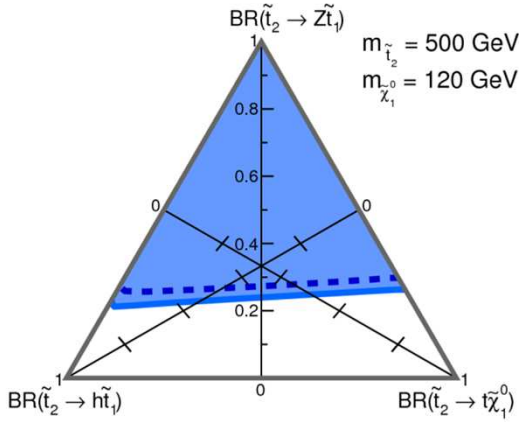
Different scenarios for χ_1^+ mass

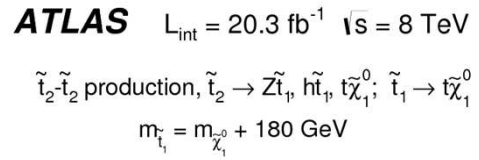
➔ Today not much white space !

3rd generation squarks : $\tilde{t}$ (3)

- **Look at every uncovered corners**
  - Vary the branching ratios 100%->50%, polarization assumptions *[ultimately pMSSM]*
  - Very compressed spectra: $\tilde{t}_1$->c $\tilde{\chi}_1^0$ **CMS-PAS-SUS-13-009, ATLAS-CONF-2013-068**
  - Top mass funel: $\tilde{t}_2$->t$\tilde{\chi}_1^0$ or $\tilde{t}_2$→Z/H $\tilde{t}_1$→Z/H t $\tilde{\chi}_1^0$ **1405.3886 (CMS), 1403.5222 (ATLAS)**

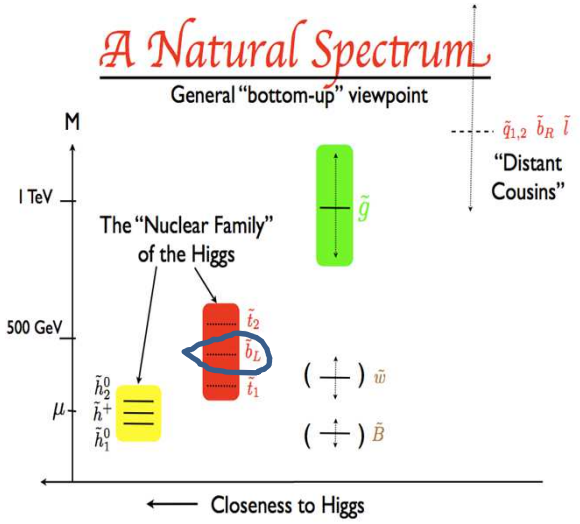






- **$\tilde{G}$=LSP also actively pursued and gives m($\tilde{t}_1$)>O(500) GeV**
  - NLSP=Higgsino-like : $\tilde{t}_1$ ->b$\tilde{\chi}_1^+$ -> bff'$\tilde{\chi}_1^0$ -> bff'h^0(->γγ,bb)$\tilde{G}$ **1312.3310 (CMS)**
  - NLSP=Higgsino-like : $\tilde{t}_1$ ->b$\tilde{\chi}_1^+$ -> bff'$\tilde{\chi}_1^0$ -> bff'h^0(->ZZ)/Z (->ll) $\tilde{G}$ **1404.5801 (CMS), 1403.5222 (ATLAS)**
  - Other NLSP scenario also looked at, e.g. $\tilde{\tau}_1$ NLSP: t_1→bν$_\tau\tilde{\tau}_1$→bν$_\tau$ν$_\tau\tau\tilde{G}$ **ATLAS-CONF-2014-014**

3rd generation squarks : $\tilde{b}$



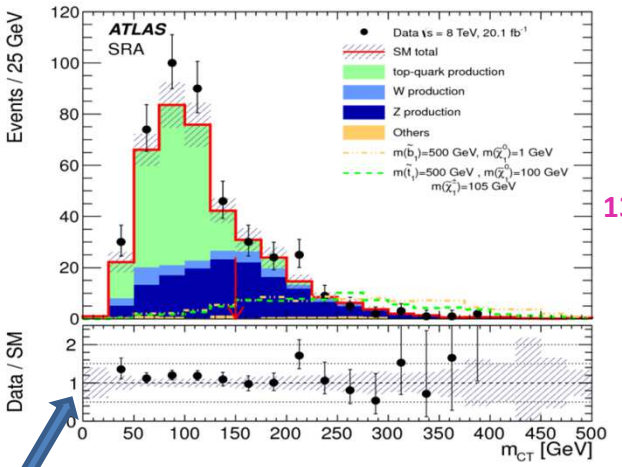
Two possible decay channels:

1- $\tilde{b} \rightarrow b\tilde{\chi}_1^0$

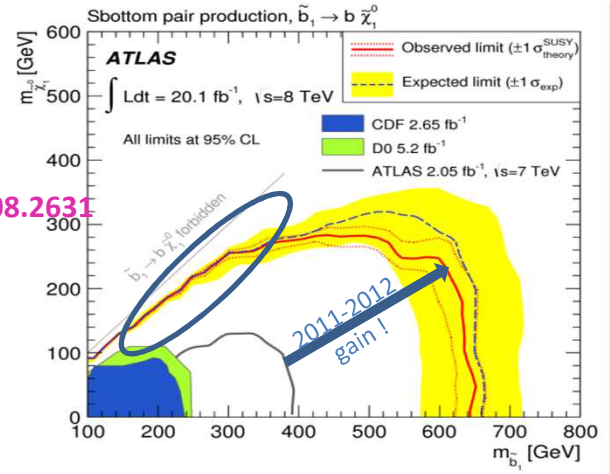
Signature: 2 b-jets + E_t^{miss}

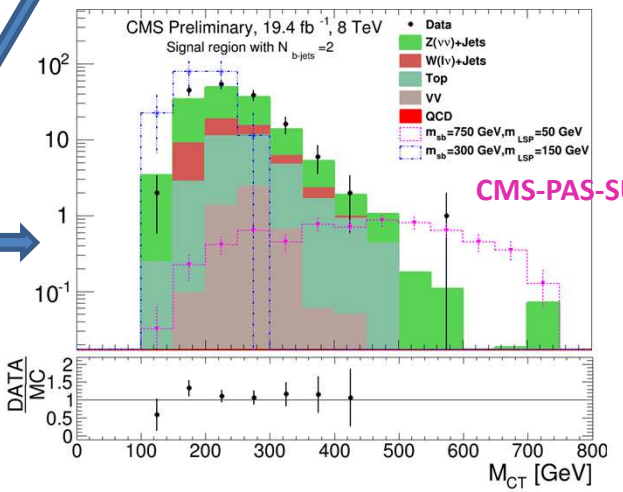
2- $\tilde{b} \rightarrow t\tilde{\chi}_1^{+/-} \rightarrow bWW^*\tilde{\chi}_1^0$

Signature: 2 like-sign leptons + E_t^{miss} + 2 bjets

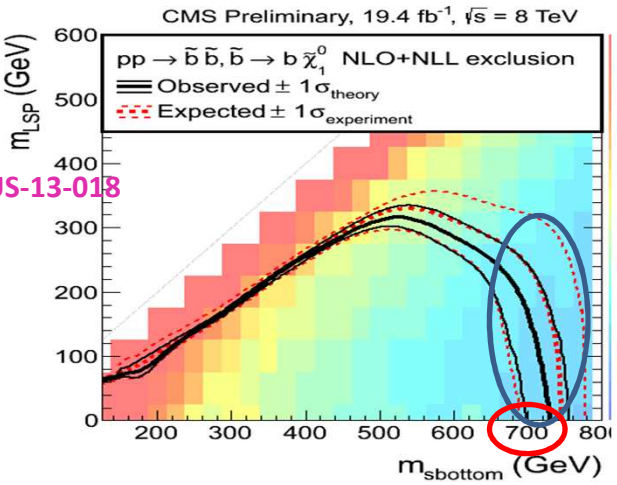


1308.2631





CMS-PAS-SUS-13-018



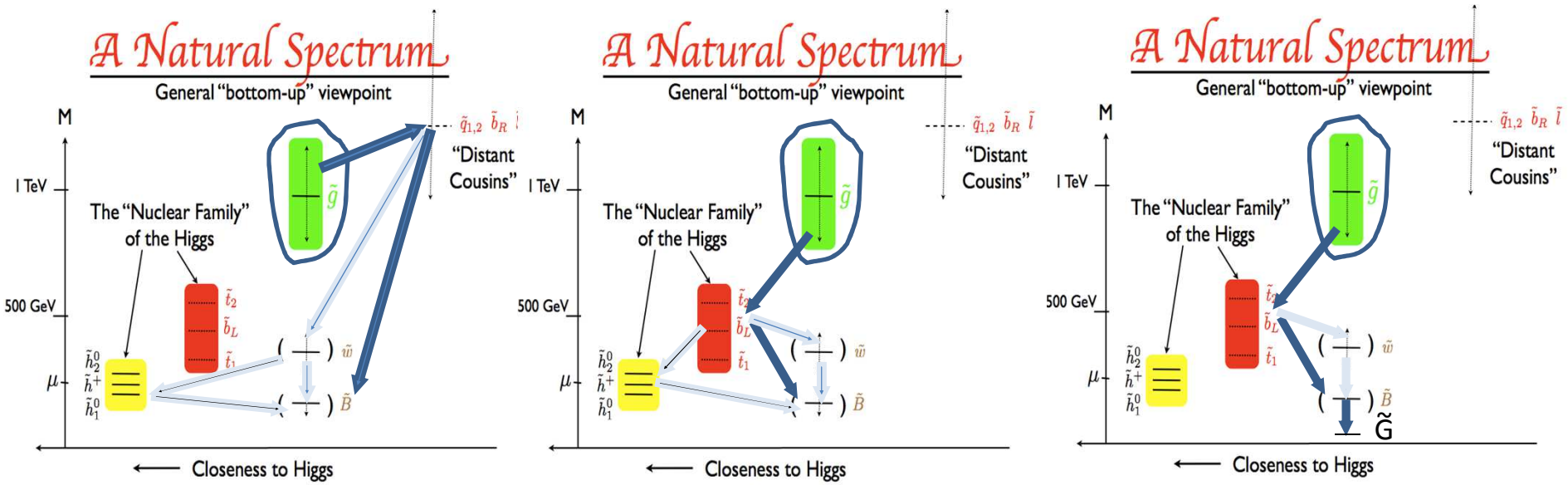
Seriously bites in the naturalness area !

Similar for $\tilde{b} \rightarrow t\tilde{\chi}_1^+$ and $\tilde{G}$=LSP (covered by $\tilde{G}$=LSP stop searches)

Gluinos searches

See more in S. Versille's talk

1, 2, 3 or 4-step decays

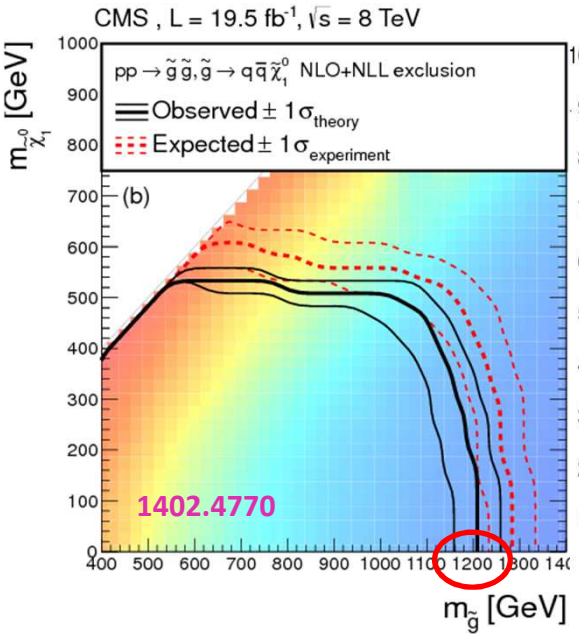


Note: These searches also address 1st/2nd generation squarks (see back-up for more details)

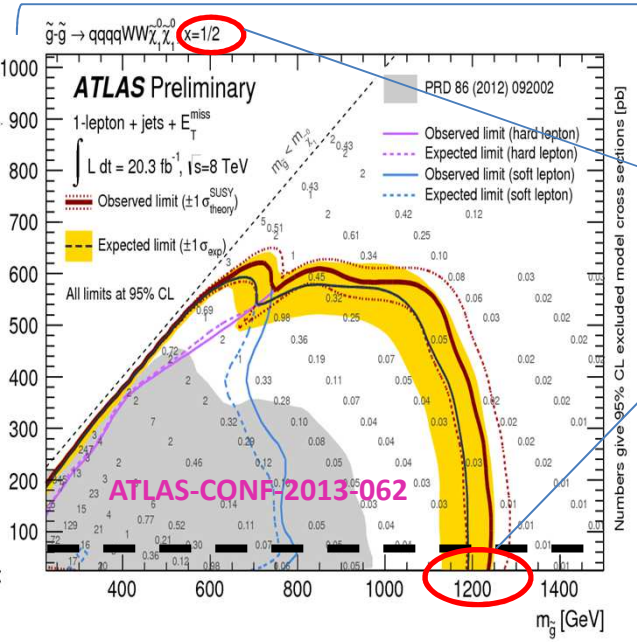
Gluinos searches (1)

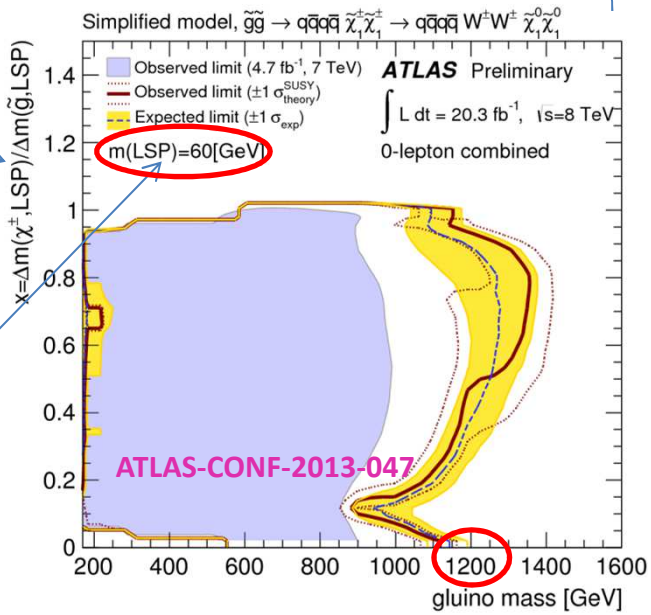
- **With $\tilde{\chi}_1^0$=LSP, consider $\tilde{g} \rightarrow q\bar{q}^{(*)} \rightarrow qq\tilde{\chi}_1^0$ / $qqW\tilde{\chi}_1^0$ [$\tilde{q}$=1rst/2nd generation]**
  - With **2-10** high energetic **jets** + E_T^{miss} : cover at best compressed / open spectra
  - To maximize coverage, split in number of **leptons** (0, 1, 2 generally like-sign)

1 step decay



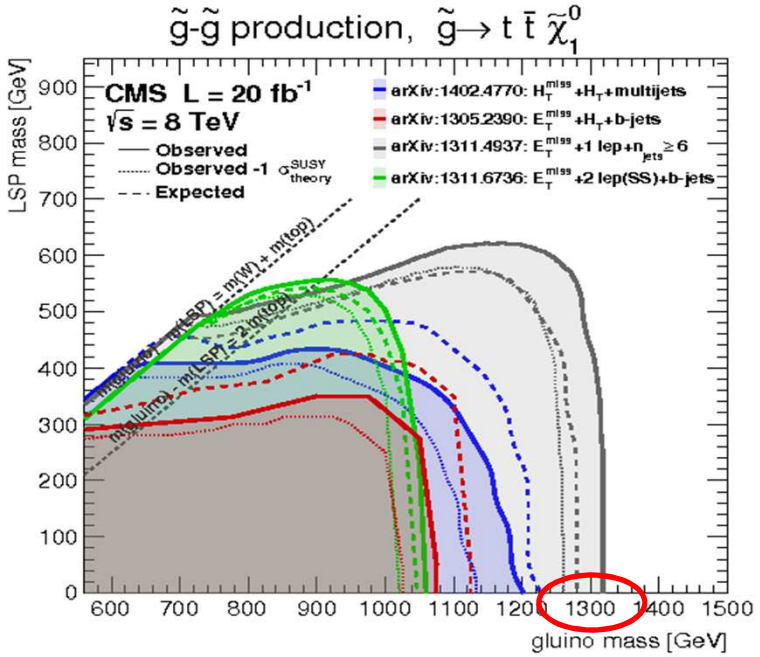
2 step decay

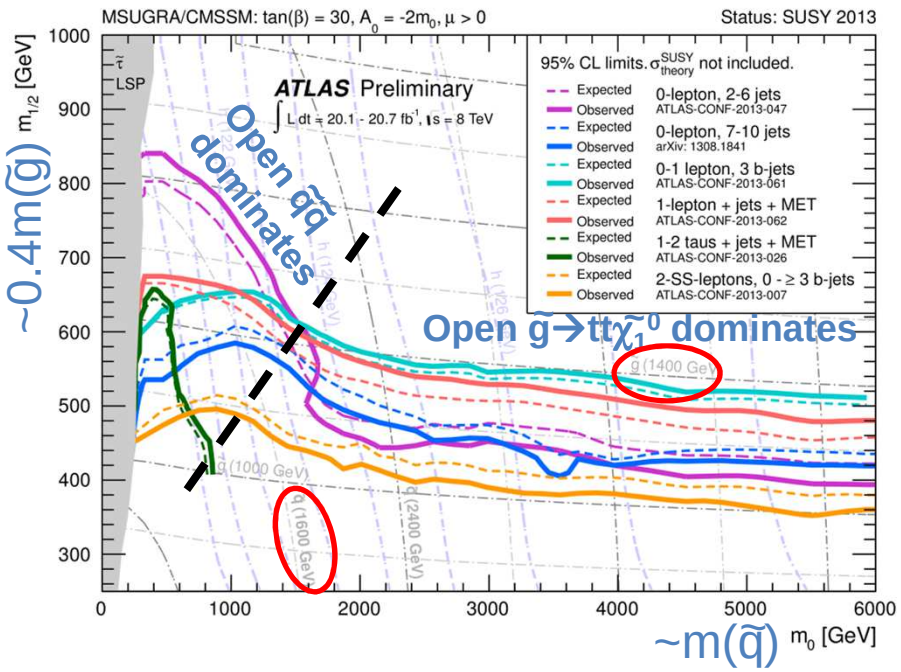




Gluinos searches (2)

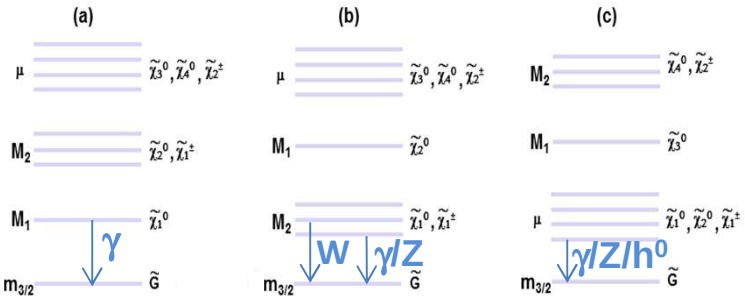
- **With $\tilde{\chi}_1^0$=LSP, consider $\tilde{g} \rightarrow q\tilde{q}^{(*)} \rightarrow qq\tilde{\chi}_1^0$ / $qqW\tilde{\chi}_1^0$ [$\tilde{q}$=3rd generation]**
  - With 2-10 high energetic jets + E_T^{miss}
  - Split in number of leptons (0, 1, 2 like-sign) and bjets (0-3)





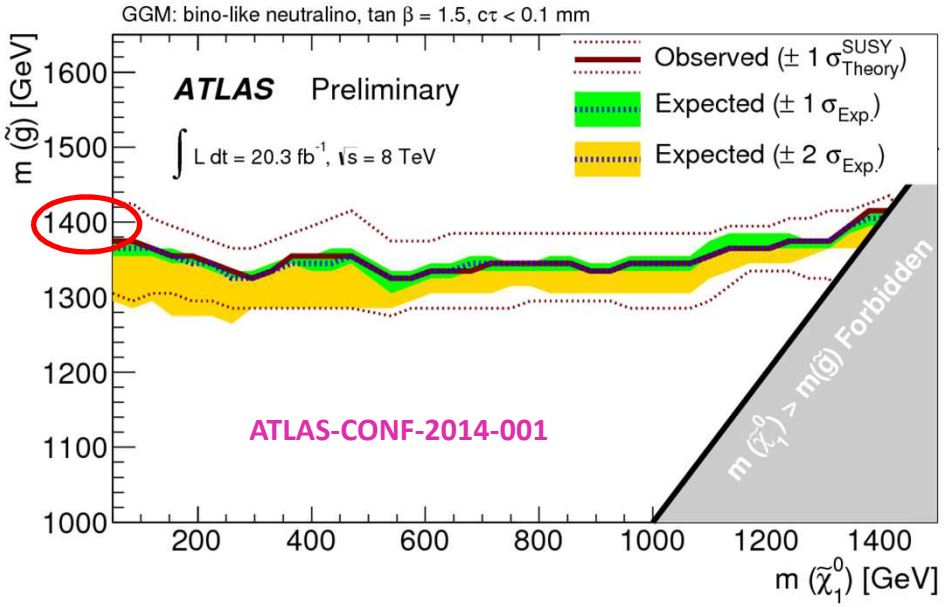
In all cases, $m(\tilde{g})$>O(1) TeV for $m(\tilde{\chi}_1^0)$>500 GeV!

Gluinos searches (3)

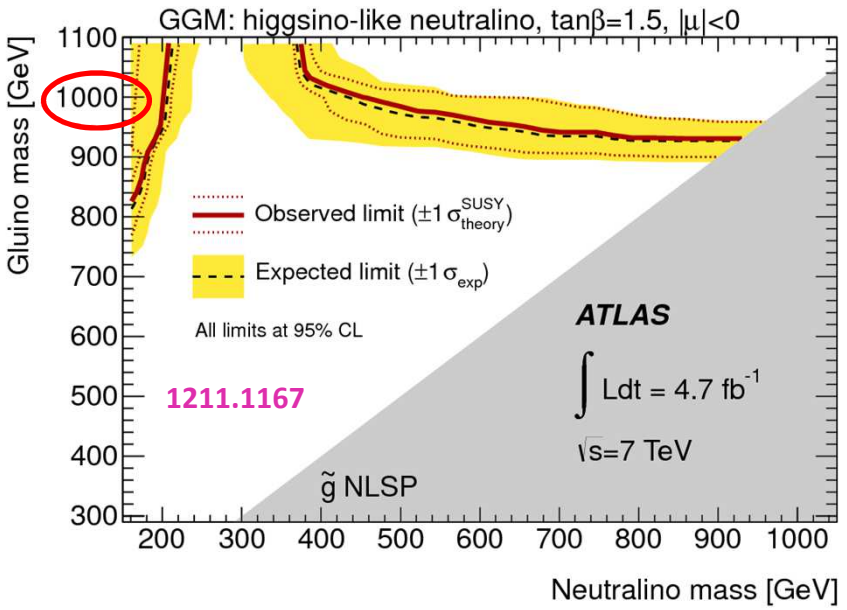


- **With $\tilde{G}$=LSP, driven by $\tilde{\chi}_1^0$ decay to $\tilde{G}$**
  - Ask many energetic jets + E_T^{miss} …
  - … as well as additional photon(s) and eventually leptons/b-jets

(a): $\gamma\gamma + E_T^{miss}$



(c): $\gamma h^0(\rightarrow 2b) + E_T^{miss}$



Here also m(g̃)>O(1) TeV …

Conclusion on natural SUSY

❑ The giraffe turns into dinosaurs ?

Weak scale SUSY still alive if :

-- compressed scenario (limits are weaker)

-- complicated SUSY spectrum (intricate decay chains)

-- hard at low luminosity ($\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow WW\tilde{\chi}_1^0\tilde{\chi}_1^0$), Higgs in cascade

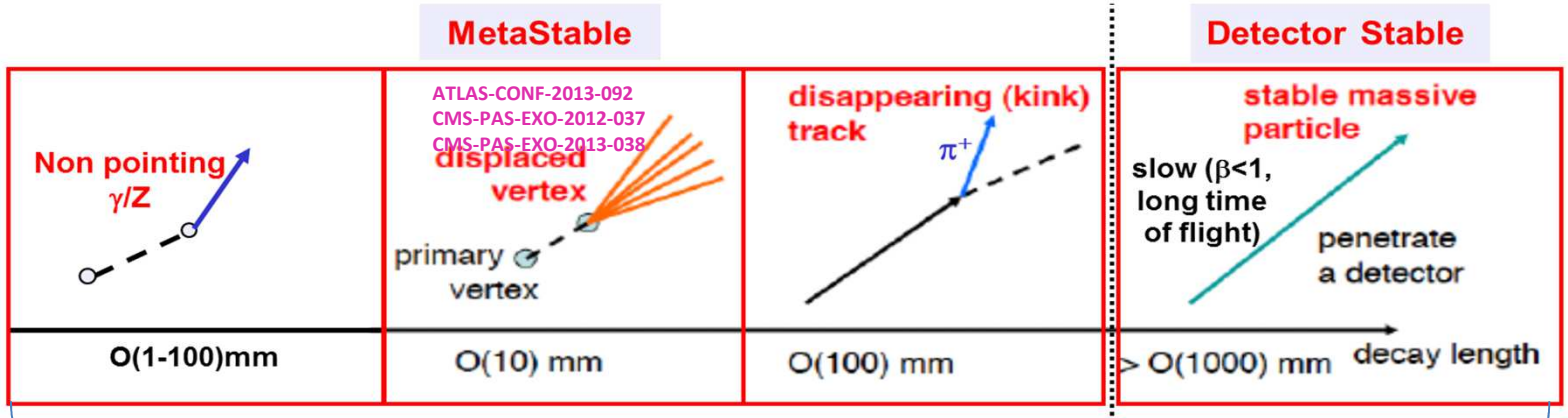
❑ Other escape routes provides extra signature at LHC

- **Vestige of SUSY spectrum at O(TeV) :**
  Generally comes with “long”-lived particles
- **R-Parity Violation:** Multileptons, No Z, multijet resonances, Lepton Flavor Violation
- **Beyond MSSM:** additional scalar particle(s)

➔ Generally background free searches !

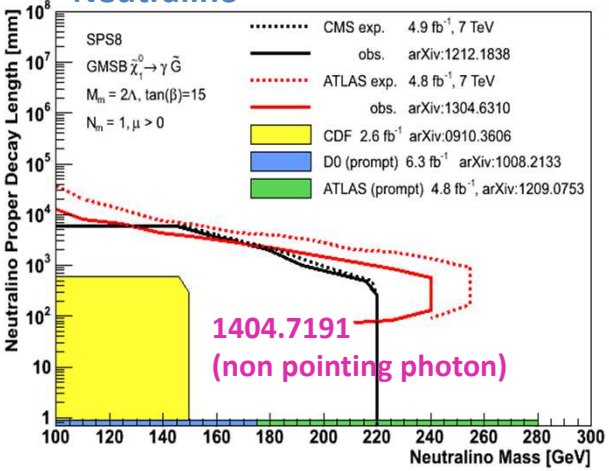
Long-Lived Particles

See more in I. Tomalin's talk

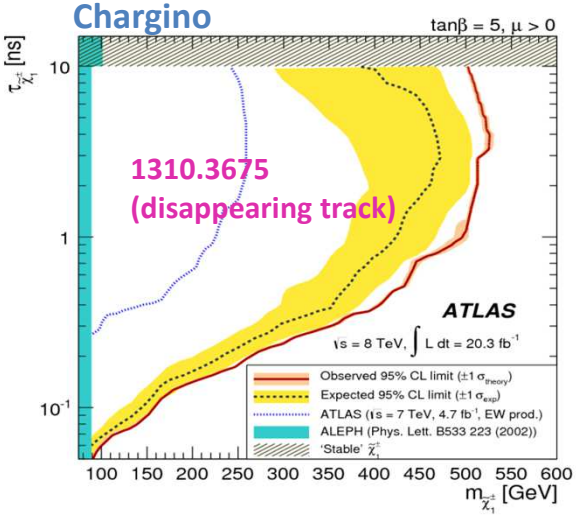


Lifetime-Mass limits

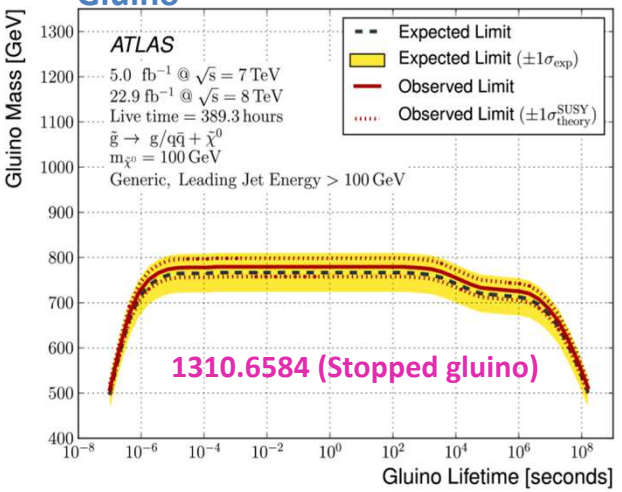
Neutralino



Chargino



Gluino



See also 1305.0491 (CMS), 1211.1597 (ATLAS), ATLAS-CONF-2013-058

R-Parity Violation

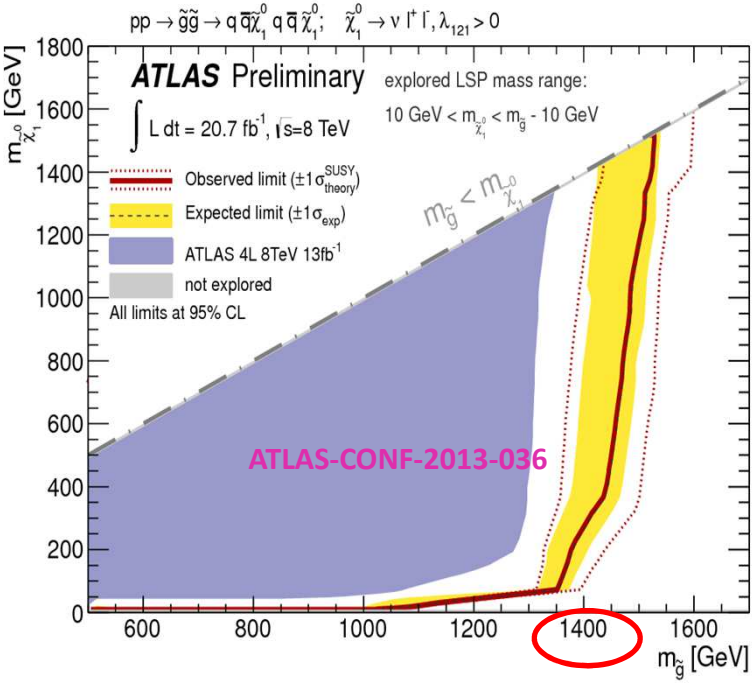
See more in R. Franceschini's talk

- **R-parity violating search at LHC** *(48 new Yukawa couplings)*

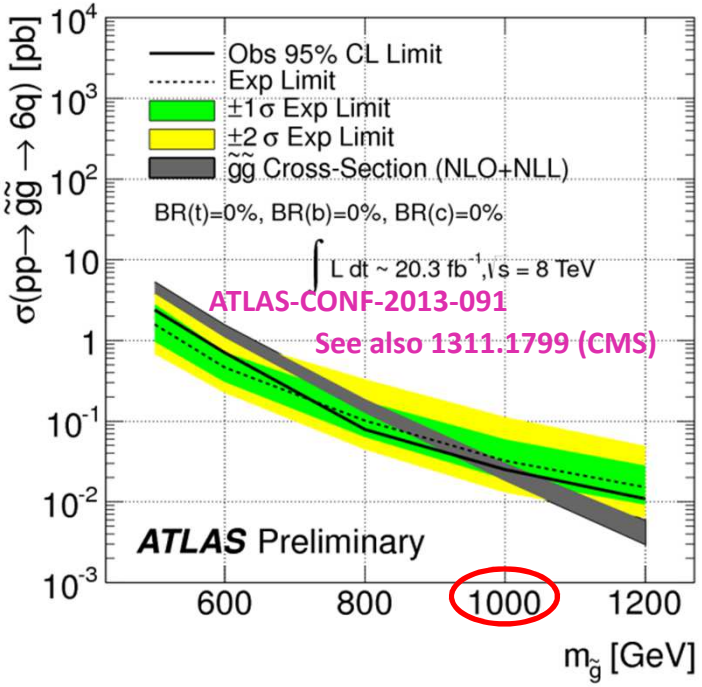
$$W = W_{MSSM} + \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\text{Lepton Number Violation (LFV)}} + \kappa_i L_i H_u + \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{Baryon Number Violation (BNV)}}$$

Ex: if one $\lambda \neq 0$ and $\tilde{\chi}_1^0$ is the LSP → spectacular signature for $\tilde{g}\tilde{g}$

$\lambda_{121} \neq 0$ implies $\tilde{\chi}_1^0 \rightarrow e\mu\nu$ ➔ ≥4 lepton

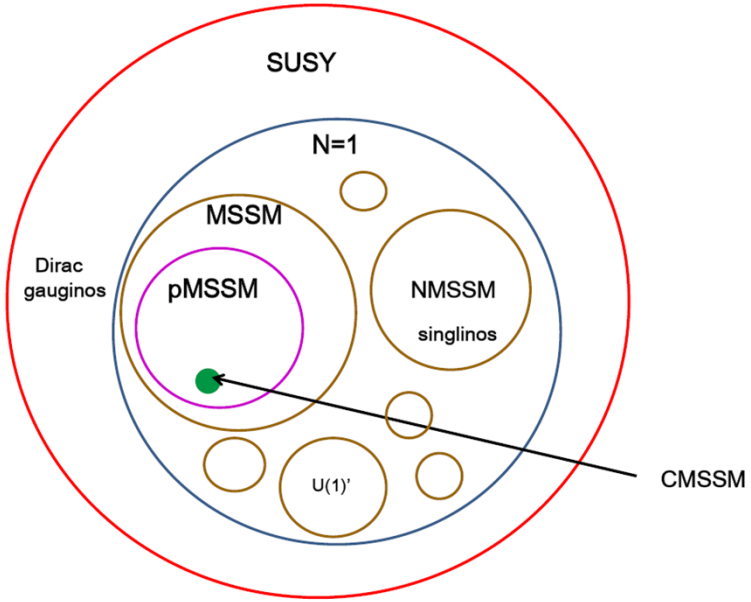


$\lambda''_{111} \neq 0$ implies $\tilde{\chi}_1^0 \rightarrow uuu$ ➔ 2x3 resonant jets



Beyond MSSM

SUSY can be realized in other ways



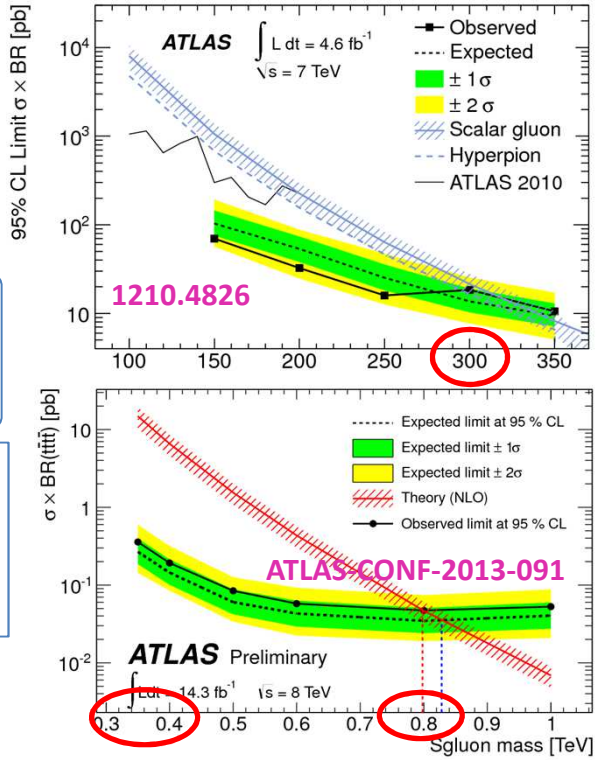
T. Rizzo (SLAC Summer Institute, 01-Aug-12)

❑ Dirac gauginos in N=2 → scalar gluons (sg)

M(sg)<350 GeV
sg→qq
2x2resonant jets

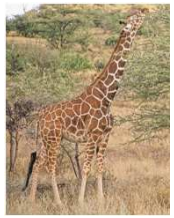
N=2 supermultiplet $\begin{pmatrix} g \\ \tilde{g} \\ sg \end{pmatrix}$

M(sg)>350 GeV
sg→tt
2 like-sign leptons



❑ Add a new singlet: NMSSM, Stealth SUSY

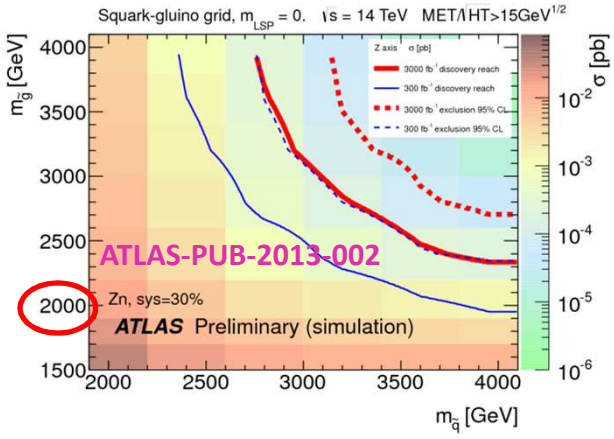
Relax Higgs mass constraint, remove E_T^{miss}, add more leptons / γ / b-jets … (see e.g. **1210.2052**)

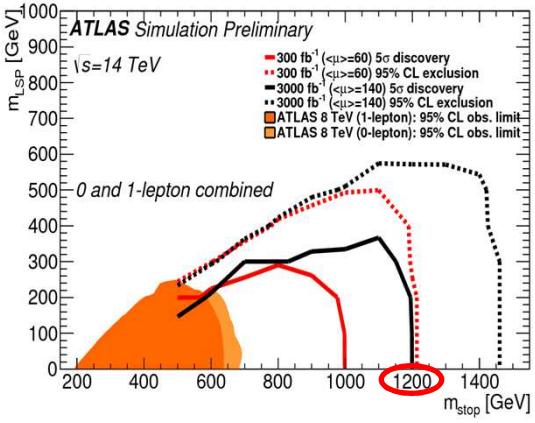


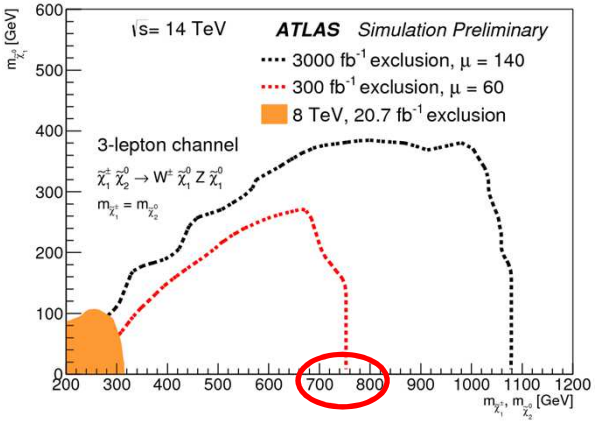
Conclusions

- **Particle Physics is truly beautiful and SUSY serves a natural purpose**
  - →From LHC run1 results, seems not the case for plain vanilla SUSY (RPC, LSP=$\tilde{\chi}_1^0/\tilde{G}$ open spect.)
    - Strongest conclusion: **Gluino** mass limit above 1 TeV in "all" cases
    - **Stop/Sbottom$_L$** not present below 500 GeV – still hidding ?
    - **EWKino** sector still model dependent. Need more luminosity
- **Still many ways to escape current limits …**
  - With LHC next run, ATLAS/CMS will continue to explore this uncharted territory !

ATLAS-PUB-2013-011





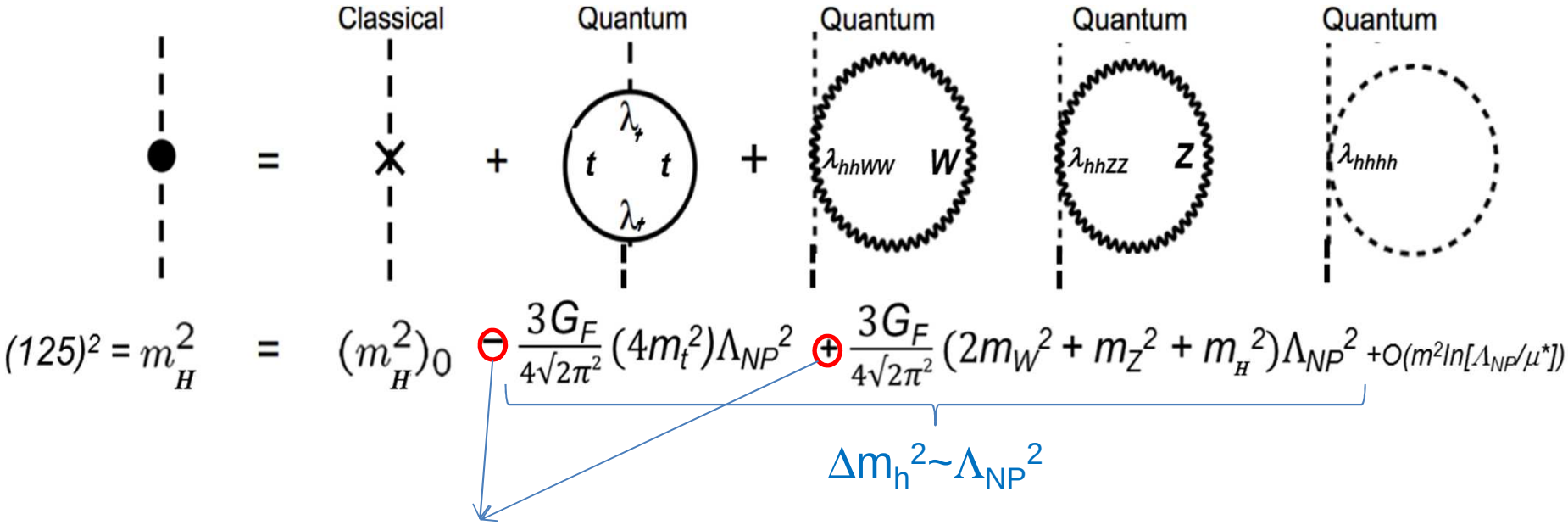


"It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so. " (M. Twain)

SPARE

Naturalness (1)

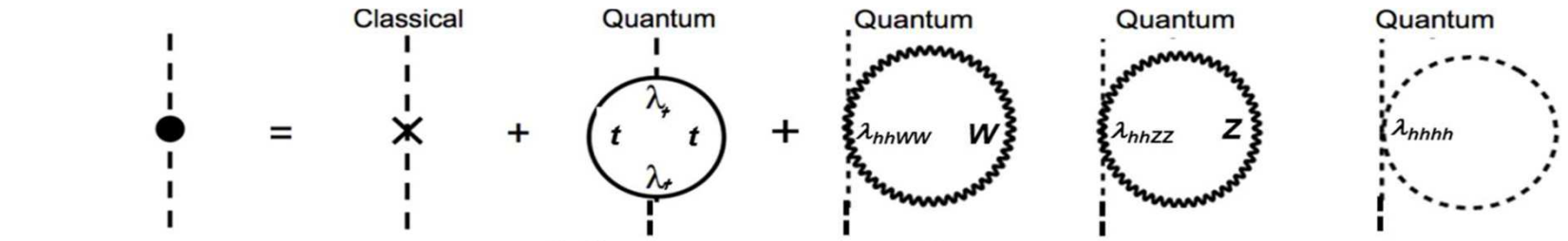
- **Particle physics is truly beautiful, SUSY serves a natural purpose...**
  - Standard Model (SM) is an effective field theory valid up to Λ_{NP} M. Veltman, Acta Phys. Polon. B 12, 437 (1981)



If all t, W, Z, H have s-1/2 partners this could solve the problem

Naturalness (2)

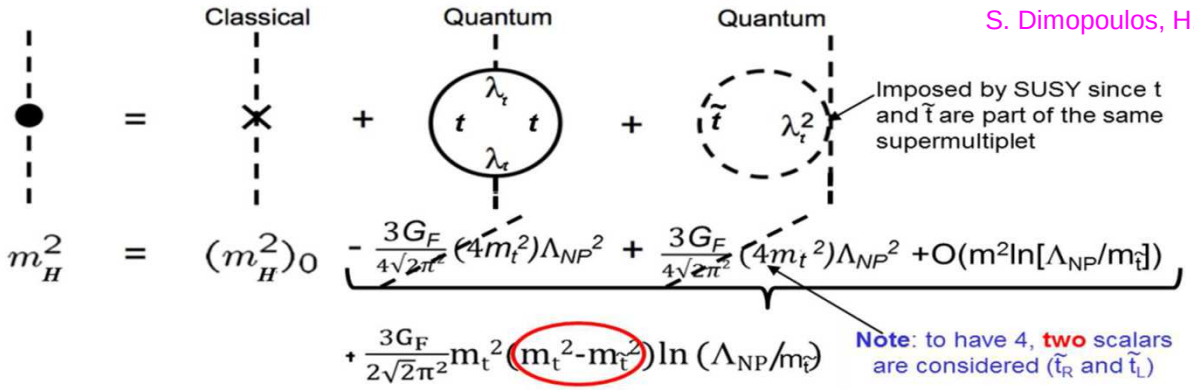
- **Particle physics is truly beautiful, SUSY serves a natural purpose...**
  - Standard Model (SM) is an effective field theory valid up to Λ_{NP} M. Veltman, Acta Phys. Polon. B 12, 437 (1981)



$$(125)^2 = m_H^2 = (m_H^2)_0 - \frac{3G_F}{4\sqrt{2}\pi^2}(4m_t^2)\Lambda_{NP}^2 + \frac{3G_F}{4\sqrt{2}\pi^2}(2m_W^2 + m_Z^2 + m_H^2)\Lambda_{NP}^2 + O(m^2 \ln[\Lambda_{NP}/\mu^*])$$

  - SM is natural if $\Delta m_h^2 < m_h^2$ *[Veltman conditions]* ➔ LNP<500 GeV *[NP will be discovered at LHC!]*
  - Some SUSY realizations are 'natural' candidate for New Physics (NP) (e.g. for the top loop)

S. Dimopoulos, H. Georgi, Nucl. Phys. B193 (1981) 150



$$m_H^2 = (m_H^2)_0 - \frac{3G_F}{4\sqrt{2}\pi^2}(4m_t^2)\Lambda_{NP}^2 + \frac{3G_F}{4\sqrt{2}\pi^2}(4m_t^2)\Lambda_{NP}^2 + O(m^2 \ln[\Lambda_{NP}/m_{\tilde{t}}])$$

$$+ \frac{3G_F}{2\sqrt{2}\pi^2} m_t^2 (m_t^2 - m_{\tilde{t}}^2) \ln(\Lambda_{NP}/m_{\tilde{t}})$$

All 8 TeV/20 fb^{-1} ATLAS/CMS results

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

9+23

Short Title of Paper	Date	√s (TeV)	L (fb^{-1})	Document	Plots+Aux. Material	Journal
2 same-sign / 3 -leptons + 0-3 b-jets + Etmiss [Incl. squarks & gluinos] NEW	4/2014	8	20.3	1404.2500	Link	Submitted to JHEP
2 leptons (e,mu) + Etmiss [chargino/neutralino/slepton] NEW	3/2014	8	20.3	1403.5294	Link	Submitted to JHEP
Z + b-jet + jets + Etmiss [Stop in GMSB, stop2] NEW	3/2014	8	20.3	1403.5222	Link	Submitted to EPJC
2 leptons + (b)jets + Etmiss [stop] NEW	3/2014	8	20.3	1403.4853	Link	Submitted to JHEP
3 leptons (e,mu,tau) + Etmiss [chargino/neutralino] NEW	2/2014	8	20.3	1402.7029	Link	Accepted by JHEP
Long-lived stopped gluino or squark R-hadrons [Split-SUSY]	10/2013	7+8	27.9	1310.6584	Link	Phys. Rev. D 88, 112003 (2013)
Disappearing track + jets + Etmiss [Direct long-lived charginos - AMSB]	10/2013	8	20.3	1310.3675	Link	Phys. Rev. D 88, 112006 (2013)
0 leptons + 2 b-jets + Etmiss [Sbottom/stop]	08/2013	8	20.1	1308.2631	Link	JHEP 10 (2013) 189
0 leptons + >=7-10 jets + Etmiss [Incl. squarks & gluinos]	08/2013	8	20.3	1308.1841	Link	JHEP 10 (2013) 130

Short Title of preliminary conference note	*Date*	*√s (TeV)*	*L (fb^{-1})*	*Document*	*Plots*
Stop in b, tau and gravitino NEW	03/2014	8	20.3	*ATLAS-CONF-2014-014*	*Link*
General new phenomena search NEW	03/2014	8	20.3	*ATLAS-CONF-2014-006*	*Link*
2 photons + Etmiss [GGM]	01/2014	8	20.3	*ATLAS-CONF-2014-001*	*Link*
1 lepton + bb(H) + Etmiss [EW production]	08/2013	8	20.3	*ATLAS-CONF-2013-093*	*Link*
Muon + displaced vertex [RPV]	08/2013	8	20.3	*ATLAS-CONF-2013-092*	*Link*
Multijets [RPV]	08/2013	8	20.3	*ATLAS-CONF-2013-091*	*Link*
2 leptons + jets + Etmiss [incl. squarks & gluinos]	08/2013	8	20.3	*ATLAS-CONF-2013-089*	*Link*
0 leptons + mono-jet/c-jets + Etmiss [Stop in charm+LSP]	07/2013	8	20.3	*ATLAS-CONF-2013-068*	*Link*
2 leptons + (b)jets + Etmiss [Medium stop, MVA]	07/2013	8	20.3	*ATLAS-CONF-2013-065*	*Link*
1-2 leptons + 3-6 jets + Etmiss [Incl. squarks & gluinos, mUED]	06/2013	8	20.3	*ATLAS-CONF-2013-062*	*Link*
0-1 leptons + >=3 b-jets + Etmiss [3rd gen. squarks]	06/2013	8	20.1	*ATLAS-CONF-2013-061*	*Link*
Long-lived sleptons	06/2013	8	15.9	*ATLAS-CONF-2013-058*	*Link*
2 leptons + Etmiss [EW production]	05/2013	8	20.3	*ATLAS-CONF-2013-049*	*Link*
0 leptons + 2-6 jets + Etmiss [Incl. squarks & gluinos]	05/2013	8	20.3	*ATLAS-CONF-2013-047*	*Link*
2 leptons (+ jets) + Etmiss [Medium stop]	05/2013	8	20.3	*ATLAS-CONF-2013-048*	*Link*
1 lepton + 4(1 b-)jets + Etmiss [Medium / heavy stop]	03/2013	8	20.7	*ATLAS-CONF-2013-037*	*Link*
3 leptons + Etmiss [EW production]	03/2013	8	20.7	*ATLAS-CONF-2013-035*	*Link*
4 leptons + Etmiss [EW production, RPV]	03/2013	8	20.7	*ATLAS-CONF-2013-036*	*Link*
0 lepton + 6 (2 b-)jets + Etmiss [Heavy stop]	03/2013	8	20.5	*ATLAS-CONF-2013-024*	*Link*
Z + b-jet + jets + Etmiss [Stop in GMSB, stop2]	03/2013	8	20.7	*ATLAS-CONF-2013-025*	*Link*
1-2 taus + jets + Etmiss [GMSB]	03/2013	8	20.7	*ATLAS-CONF-2013-026*	*Link*
2 taus + Etmiss [EW production]	03/2013	8	20.7	*ATLAS-CONF-2013-028*	*Link*
2 same-sign leptons + 0-3 b-jets + Etmiss	03/2013	8	20.7	*ATLAS-CONF-2013-007*	*Link*

11+18

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
Search for top-squark pair production with Higgs and Z bosons in the final state in pp collisions at 8 TeV	SUS13024	CMS-SUS-13-024	19.5/fb	Submitted to PLB arXiv:1405.3886 NEW
Search for anomalous production of events with three or more leptons in pp collisions at 8 TeV	SUS13002	CMS-SUS-13-002	19.5/fb	Submitted to PRD arXiv:1404.5801 NEW
Search for New Physics in Multijets and Missing Momentum Final State in pp collisions at 8 TeV	SUS13012	CMS-SUS-13-012	19.5/fb	Accepted by JHEP arXiv:1402.4770
Search for SUSY Partners of Top and Higgs Using Diphoton Higgs Decays in pp collisions at 8 TeV	SUS13014	CMS-SUS-13-014	19.5/fb	Accepted by PRL arXiv:1312.3310
Search for new physics in events with same-sign dileptons and jets in pp collisions at 8 TeV	SUS13013	CMS-SUS-13-013	19.5/fb	JHEP 01 (2014) 163 arXiv:1311.6736
Search for supersymmetry using events with a single lepton, multiple jets, and b-tags	SUS13007	CMS-SUS-13-007	19.3/fb	Submitted to PLB arXiv:1311.4937
Search for top-squark pair production in the single lepton final state in pp collisions at 8 TeV	SUS13011	CMS-SUS-13-011	19.5/fb	EPJC 73 (2013) 2677 arXiv:1308.1586
Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags	SUS13003	CMS-SUS-13-003	19.5/fb	PRL 111, 221801 (2013), arXiv:1306.6643
Search for supersymmetry using the shape of the HT and MET, and b-jet multiplicity distributions	SUS12024	CMS-SUS-12-024	19.4/fb	PLB 725 243 (2013), arXiv:1305.2390
Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, 3, or ≥ 4 b jets in 8 TeV pp collisions	SUS12028	CMS-SUS-12-028	11.7/fb	EPJC 73 (2013) 2568, arXiv:1303.2985
Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at √s = 8 TeV	SUS12017	CMS-SUS-12-017	10.5/fb	JHEP03 (2013) 037, JHEP07(2013)041, arXiv:1212.6194

Phenomenological MSSM Interpretation of the 7 and 8 TeV results	SUS13020	PAS-SUS-13-020	19.5/fb	NEW
Search for direct production of a pair of bottom squarks	SUS13018	PAS-SUS-13-018	19.4/fb	NEW
Search for top-squark pair production with Higgs and Z bosons in the final state in pp collisions at 8 TeV	SUS13024	PAS-SUS-13-024	19.5/fb	NEW
Search for electroweak production of higgsinos in channels with two Higgs bosons decaying to b quarks in pp collisions at 8 TeV	SUS13022	PAS-SUS-13-022	19.5/fb	NEW
Search for supersymmetry in hadronic final states using MT2 with the CMS detector at 8 TeV	SUS13019	PAS-SUS-13-019	19.5/fb	NEW
Search for direct production of stops decaying to a charm and LSP using the monojet + MET final state	SUS13009	PAS-SUS-13-009	19.7/fb	NEW
Search for top squarks in multijet events with large missing momentum in pp collisions at 8 TeV	SUS13015	PAS-SUS-13-015	19.4/fb	NEW
A search for new physics in events with one lepton, high jet multiplicity and high b-tagged jet multiplicity in pp collisions at 8 TeV	SUS12015	PAS-SUS-12-015	19.3/fb	
Search for Direct Top Squark Pair Production with Higgs bosons in the Final State in pp collisions at 8 TeV	SUS13021	PAS-SUS-13-021	19.5/fb	
Search for SUSY in Opposite Sign Dilepton events, large number of jets, b-jets and MET in pp collisions at 8 TeV	SUS13016	PAS-SUS-13-016	19.7/fb	
Search for electroweak production of charginos and neutralinos in final states with a Higgs boson in pp collisions at 8 TeV	SUS13017	PAS-SUS-13-017	19.5/fb	
Search for anomalous production of events with three or more leptons in pp collisions at 8 TeV	SUS13002	PAS-SUS-13-002	19.5/fb	
Search for SUSY using razor variables in events with b-jets in pp collisions at 8 TeV	SUS13004	PAS-SUS-13-004	19.3/fb	
Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states in pp collisions at 8 TeV	SUS13006	PAS-SUS-13-006	19.5/fb	
Search for supersymmetry in the 3 lepton + b-tag final state in pp collisions at 8 TeV	SUS13008	PAS-SUS-13-008	19.5/fb	
Search for RPV SUSY in the 4-lepton final state in pp collisions at 8 TeV	SUS13010	PAS-SUS-13-010	19.5/fb	

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Search for Three-Jet Resonances In Multijet Final States NEW	arXiv: 1311.1799	20/fb	10.1016/j.physletb.2014.01.049	EXO12049
Search for Heavy Stable Charged Particles	arXiv: 1305.0491	20/fb	10.1007/JHEP07(2013)122	EXO12026

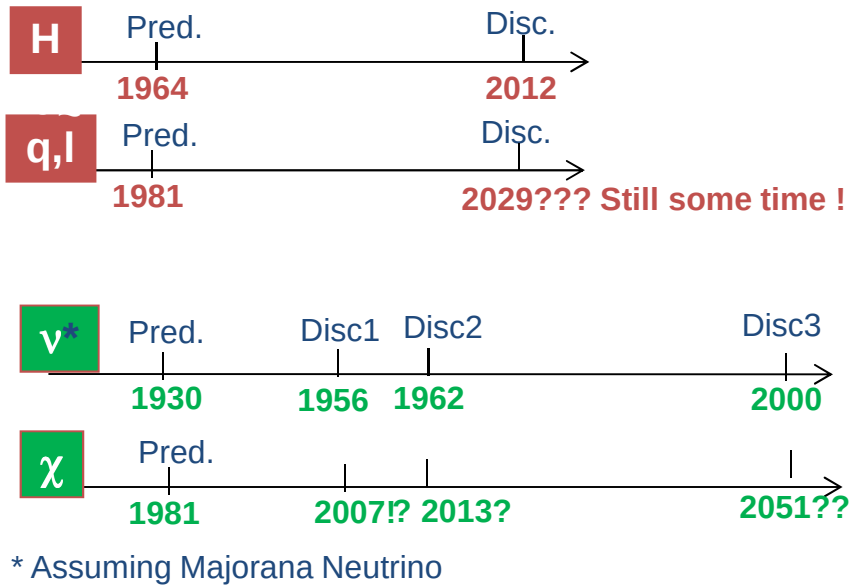
Search for displaced dilepton pairs NEW	EXO12037	PAS EXO12037	20/fb
Search for long-lived neutral particles decaying to dijets	EXO12038	PAS EXO12038	20/fb

SUSY is challenging !

- **Majorana particles and elementary scalars are generally hard to find …**
  - but constitute most of the SUSY particle spectrum !
  - So not alarming that it takes us some time …

MSSM a.k.a Weak Scale SUSY :
29 sparticles + 4 Higgs undiscovered

21! scalars + 5 Majorana + 3 others fermions



* Assuming Majorana Neutrino

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\widetilde{u}_L\ \widetilde{u}_R\ \widetilde{d}_L\ \widetilde{d}_R$ $\widetilde{s}_L\ \widetilde{s}_R\ \widetilde{c}_L\ \widetilde{c}_R$ $\widetilde{t}_L\ \widetilde{t}_R\ \widetilde{b}_L\ \widetilde{b}_R$	(same) (same) $\widetilde{t}_1\ \widetilde{t}_2\ \widetilde{b}_1\ \widetilde{b}_2$
sleptons	0	−1	$\widetilde{e}_L\ \widetilde{e}_R\ \widetilde{\nu}_e$ $\widetilde{\mu}_L\ \widetilde{\mu}_R\ \widetilde{\nu}_\mu$ $\widetilde{\tau}_L\ \widetilde{\tau}_R\ \widetilde{\nu}_\tau$	(same) (same) $\widetilde{\tau}_1\ \widetilde{\tau}_2\ \widetilde{\nu}_\tau$
neutralinos	1/2	−1	$\widetilde{B}^0\ \widetilde{W}^0\ \hat{H}\ \widetilde{h}_1^0, \widetilde{h}_2^0$	$\widetilde{N}_1\ \widetilde{N}_2\ \widetilde{N}_3\ \widetilde{N}_4$
charginos	1/2	−1	$\widetilde{W}^\pm\ \widetilde{h}^+, \widetilde{h}^-$	$\widetilde{C}_1^\pm\ \widetilde{C}_2^\pm$
gluino	1/2	−1	$\widetilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\widetilde{G}$	(same)

Excellent framework for an experimentalist → need to push his detector to the best !

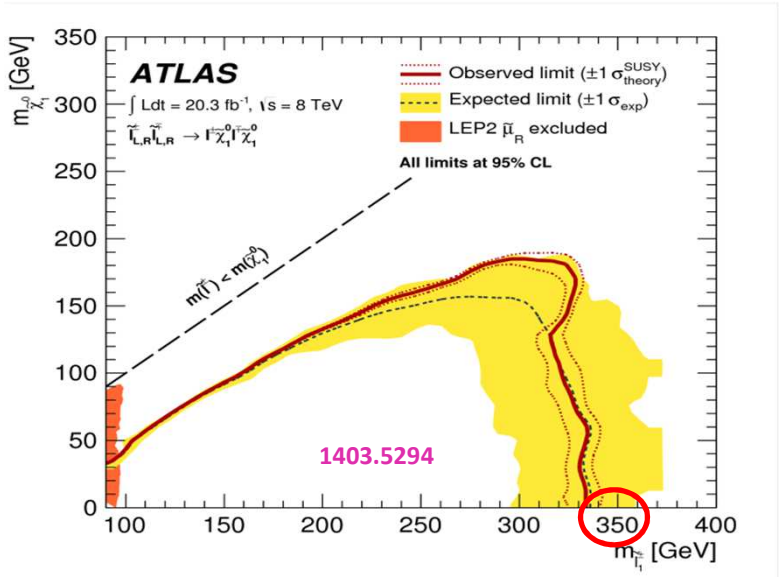
EWK SUSY: sleptons

❑ Conclusions:

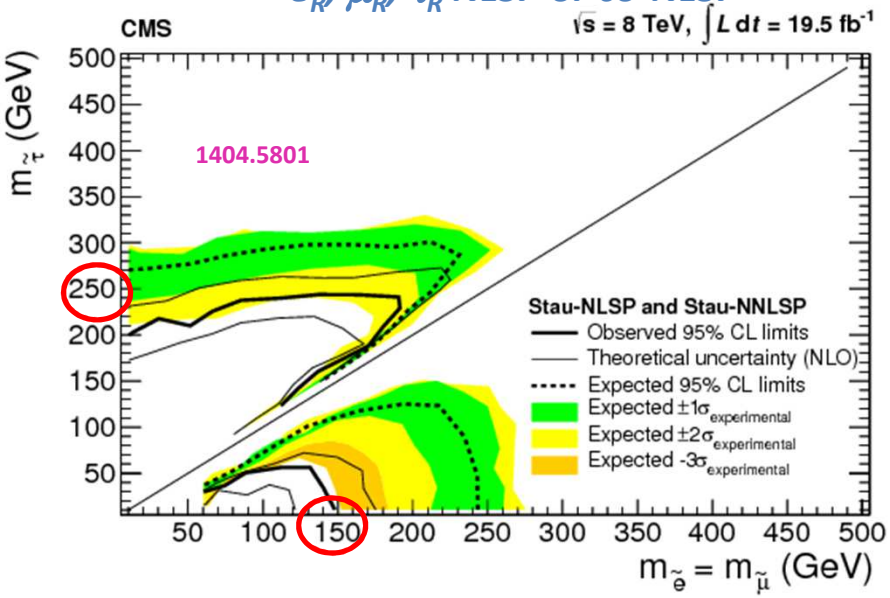
- First extensive exploration of SUSY EWK at 8 TeV but no generic mass limits
  - ✓ More final conclusions in 4D (M_1, M_2, μ, tanβ) in the making
  - ✓ Still a lot of "natural" phase space to explore …

  Note: Unsensitive to $\tilde{\chi}_1^0\,\tilde{\chi}_1^0$ production at LHC when LSP=$\tilde{\chi}_1^0$ *See more in I. Vivarelli's talk*
- Look also for direct charged sleptons production

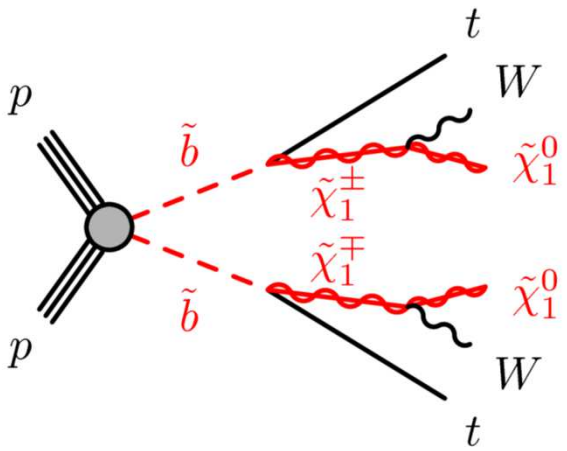
$\tilde{\chi}_1^0$=LSP [2l + E_T^{miss}]
$\tilde{l} = \tilde{e}_R, \tilde{e}_L, \tilde{\mu}_R, \tilde{\mu}_L$

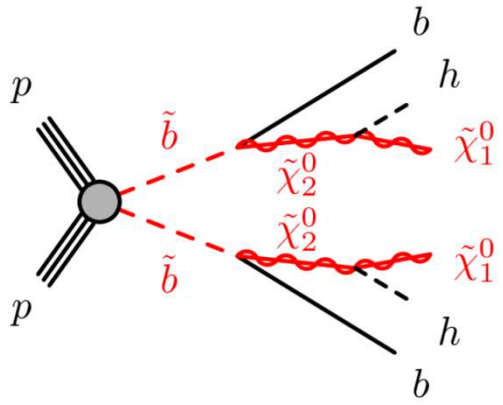


$\tilde{G}$=LSP [≥3l + E_T^{miss}]
$\tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_R$ NLSP or co-NLSP



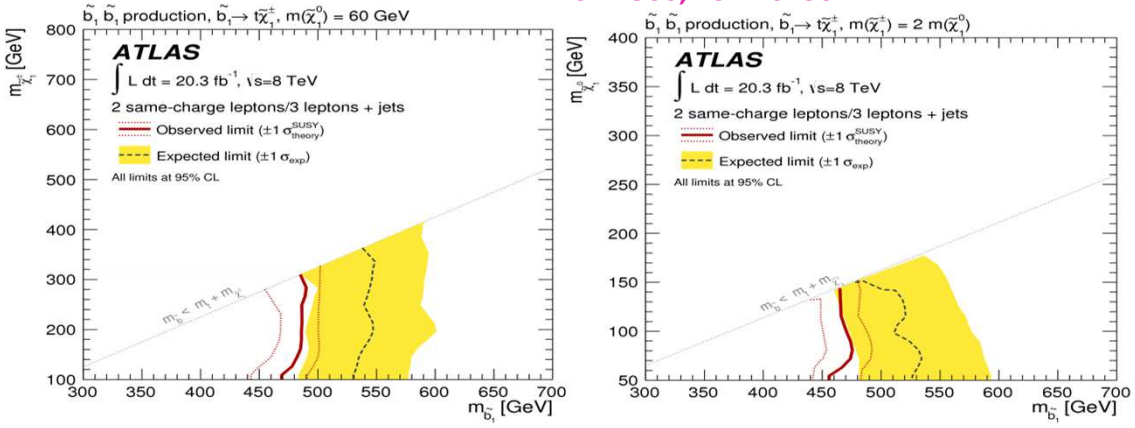
3rd generation squarks : $\tilde{b}$



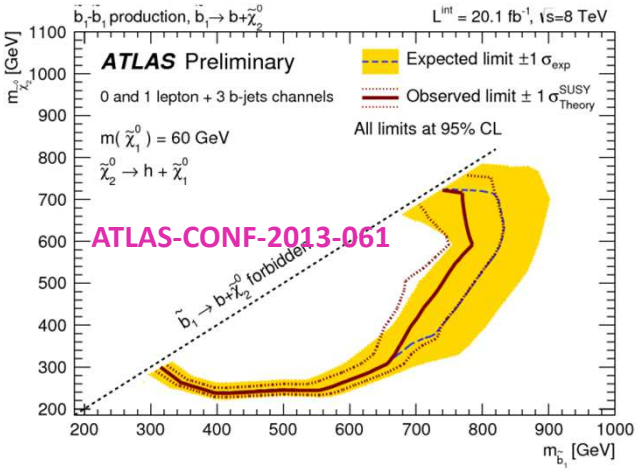


2 like-sign lepton signature

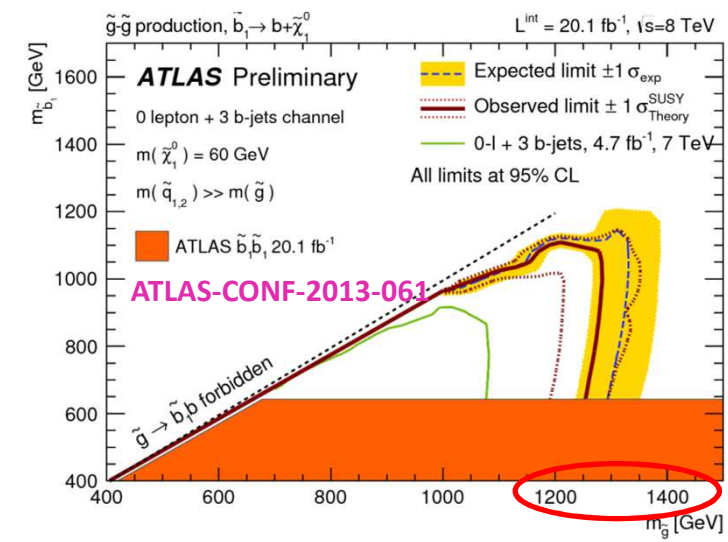
1404.2500, 1311.6736

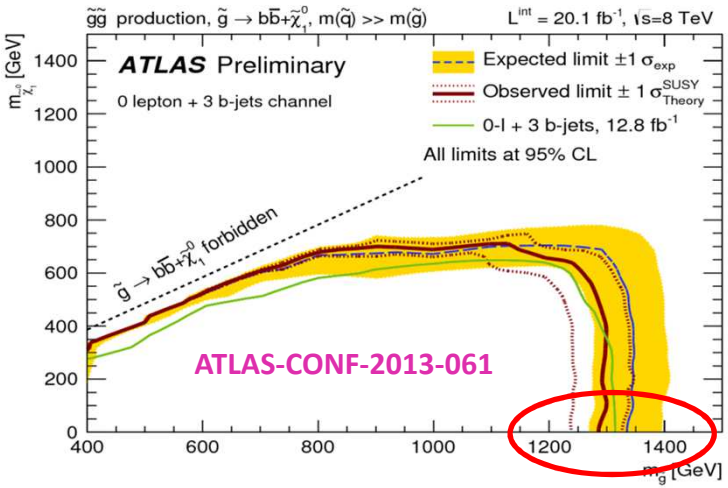


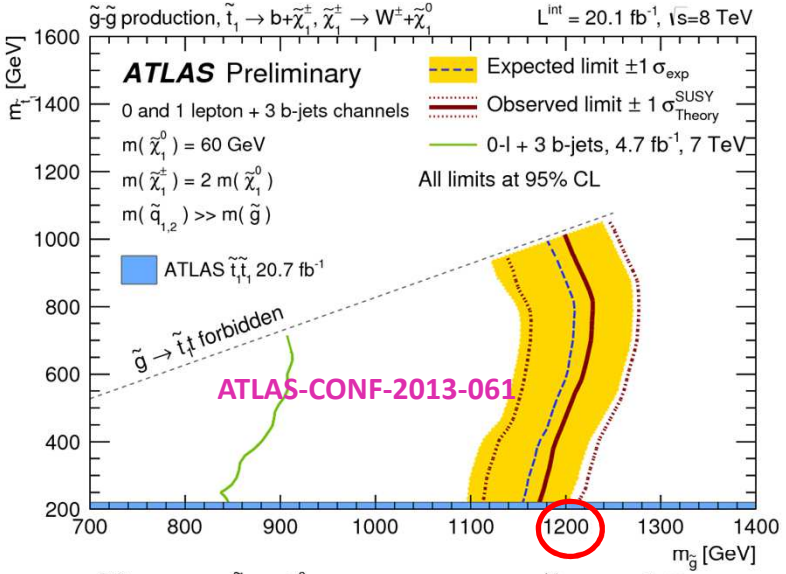
Multi-b signature (h→bb)

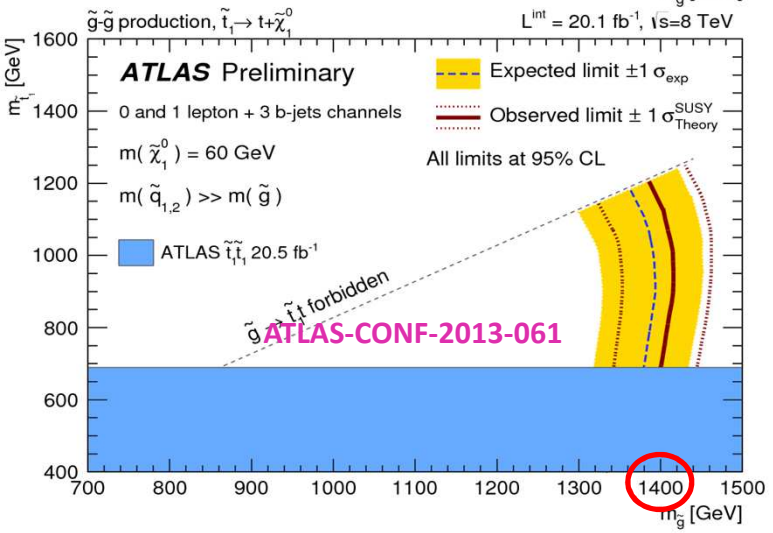


Gluinos searches

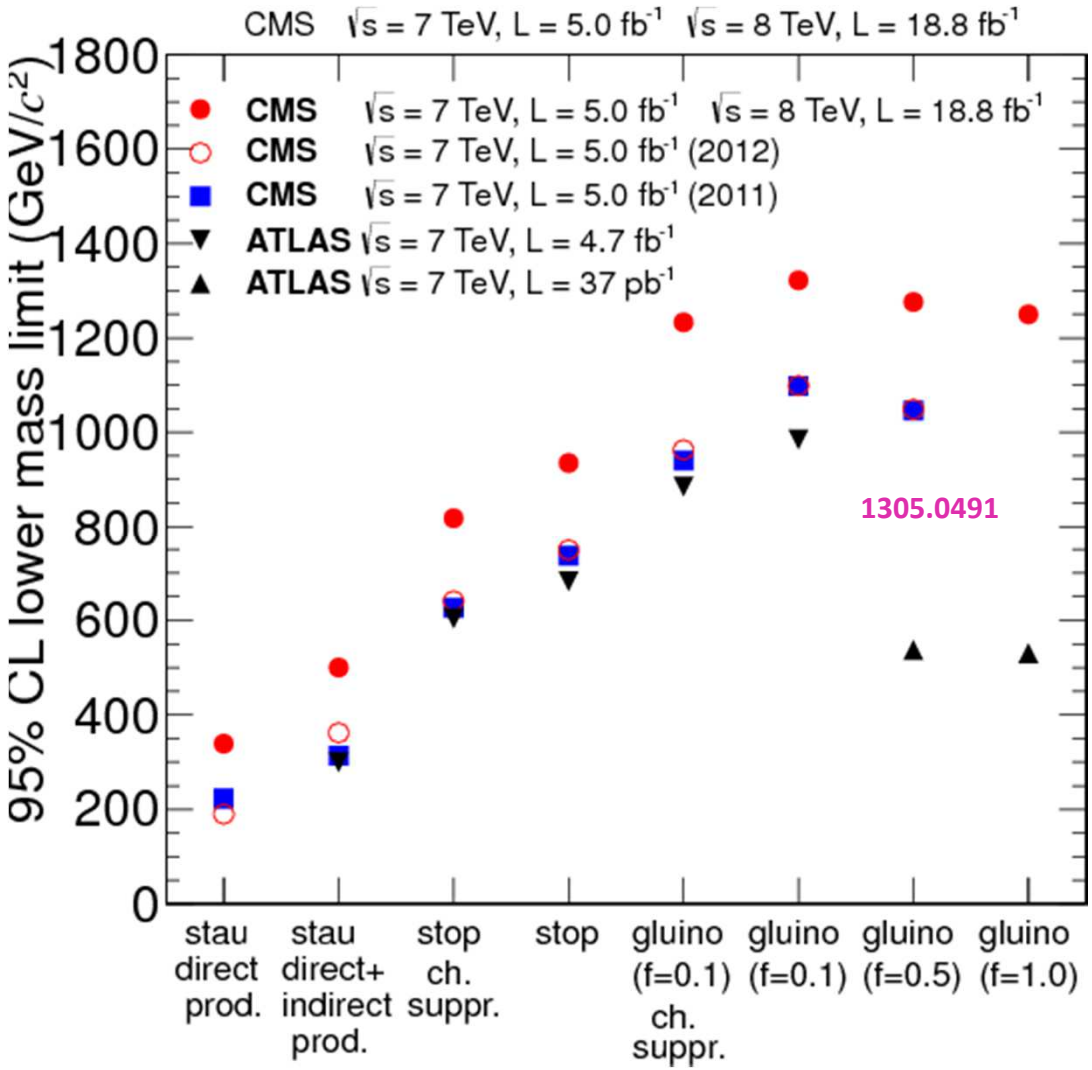




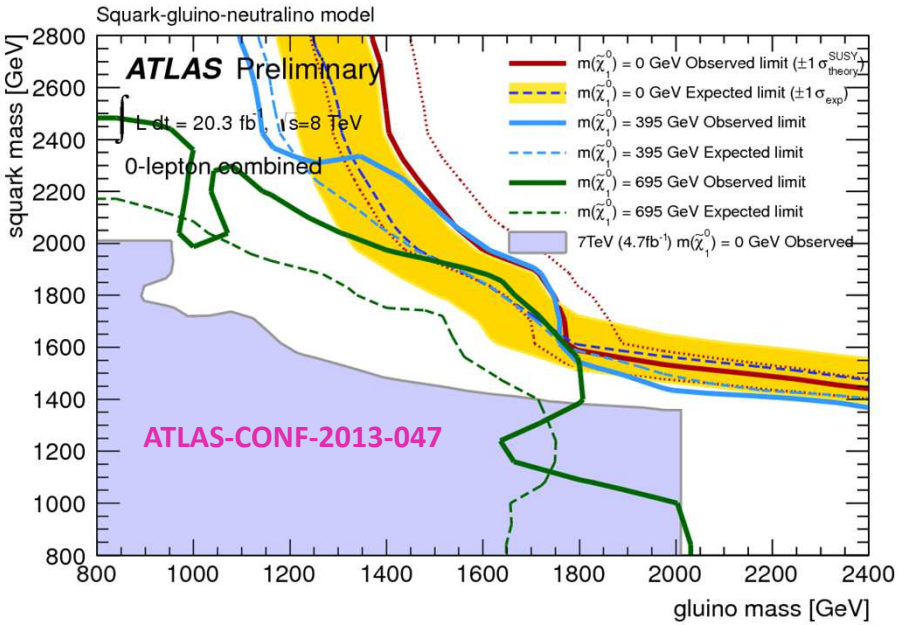


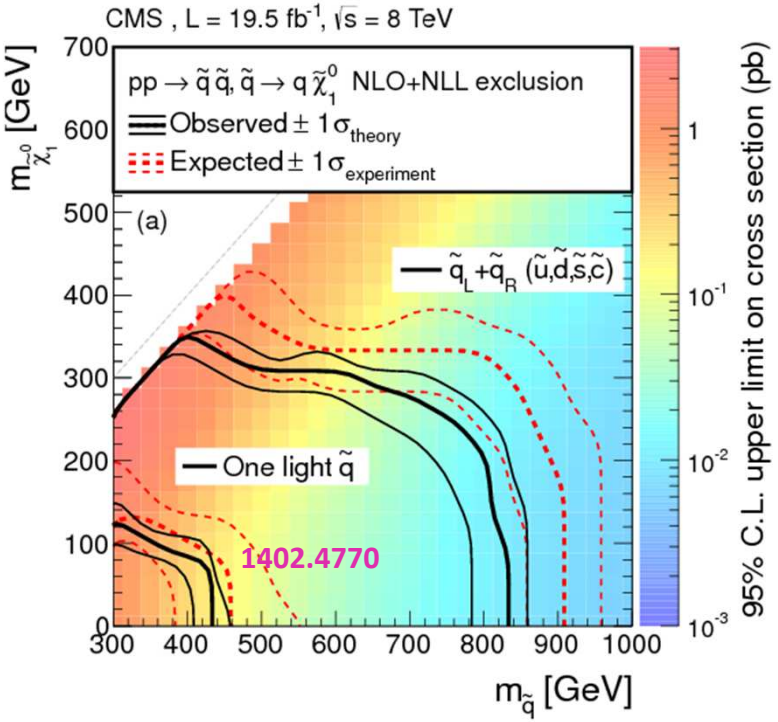


Long-lived Particles



1st/2nd generation squarks





ATLAS Learning Machine

- **Use the ATLAS experiment to identify the Higgs boson**
  - H→tautau channel
  - Use simulated data ….
  - http://www.kaggle.com/c/higgs-boson/