# SUSY Searches at ATLAS

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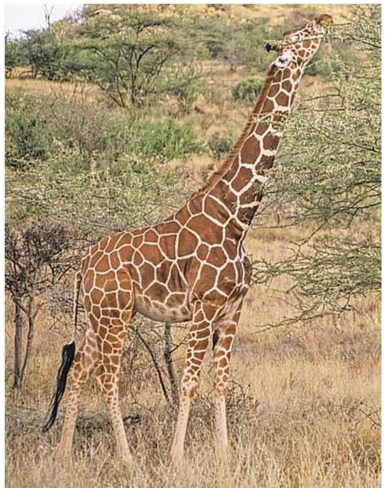


``I am sure we all agree that a giraffe is truly beautiful,
but she doesn't seem to serve any purpose"
**J. Weiss (1974)**

"Theories are like fishing : only he who casts can catch"
**Novalis (1772-1801)**

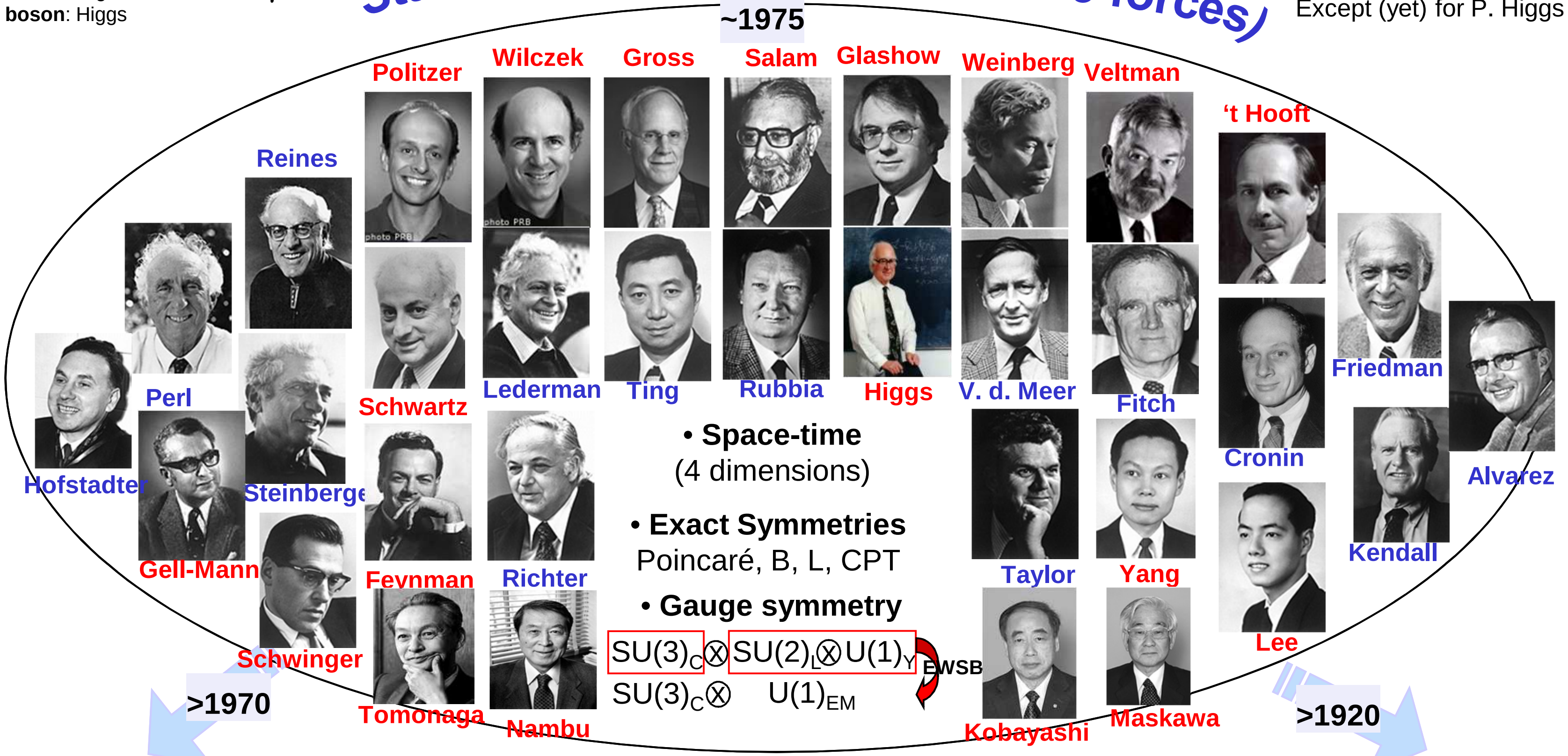

**Saclay, 3-December 2012**

# Motivation

* **3 fermion families** of (leptons/quarks$_{RGB}$)$_{LR}$
* **12 S=1 Bosons** :8 gluons, $W^+$, $W^-$, $Z^0$, $\gamma$
* **1 scalar boson**: Higgs

## Standard Model (58* particles - 3 forces)

Selected Nobel Prizes since 1957
Except (yet) for P. Higgs




## Supersymmetry (SUSY)

- New symmetry between boson & fermions (broken) following generalisation of space-time symmetries
- If low-scale SUSY, Higgs (H) mass stabilized

➔**New particles at ≈ TeV scale (2xSM) weakly coupled to H**

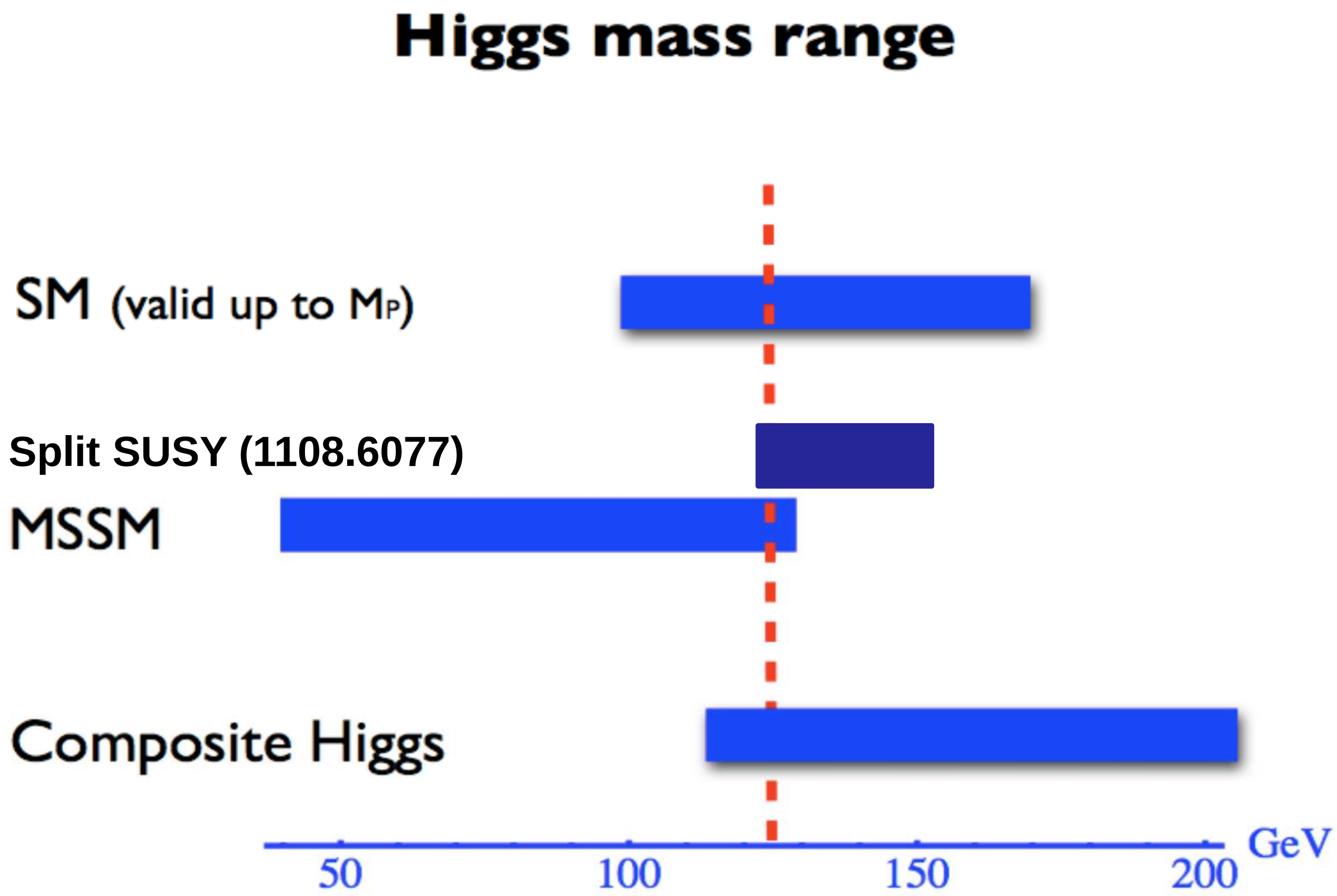
+ *Force unified at 2 $10^{16}$ GeV, Dark Matter candidate, gravitation*

## Extra Dim./Strong dynamics (AdS/CFT)

- Particle substructure and/or New space-time dimensions/interactions at higher scale
- Higgs (H) mass stabilized

➔**New particles at ≈ TeV scale, strongly coupled to H**

# New Physics after X(125) discovery

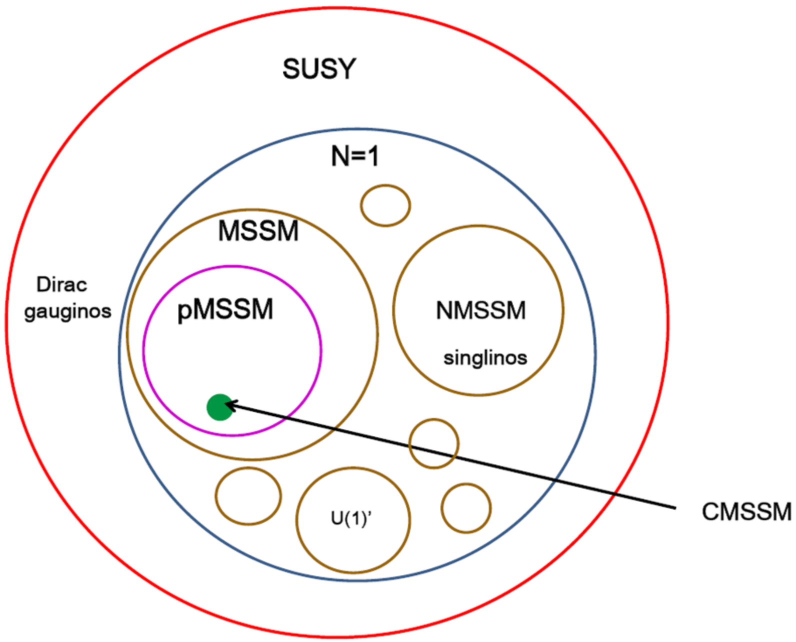



*A. Pomarol (ICHEP Plenary, July-12)*

➔ Most of New Physics models still alive (stronger constraints from Higgs couplings)

# SUSY Framework (1)

**SUSY Theory phase space**




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

**MSSM: 29 sparticles + 4 Higgs undiscovered**

| 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 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |

➔ Goal : find hints of (N)MSSM particles

# SUSY Framework (2)

## ❑ Weak-scale SUSY searches before first LHC SUSY results

**MSSM: 29 sparticles + 5 Higgs undiscovered**

**Mass Limits from PDG2010 (95% CL)**
$\tilde{\chi}_1^0$=LSP, RPC, degenerate squarks (except $\tilde{b}$,$\tilde{t}$), $\tilde{l}=\tilde{l}_R$, Gaugino mass unification at GUT scale

| Names | Spin | $P_R$ | Gauge Eigenstates | Mass Eigenstates | Mass Limits |
|---|---|---|---|---|---|
| Higgs bosons | 0 | +1 | $H_u^0\ H_d^0\ H_u^+\ H_d^-$ | $h^0\ H^0\ A^0\ H^\pm$ | 114.4 , 92.8 , 93.4 , 79.3 GeV ($m_h^{max}$ benchmark scenarios) |
| squarks | 0 | −1 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) | 379 GeV |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) | |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ | 95.7 , 89 GeV |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) | 107 GeV |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) | 94 GeV |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ | 81.9 GeV |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ | 46 , 62.4, 99.9 , 116 GeV |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ | 94 GeV |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) | 308 GeV |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) | |

Note: These limits are also model dependent

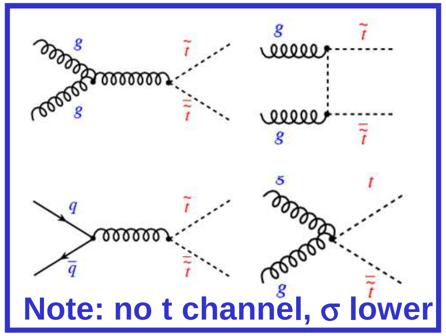
Covers most of SUSY production and decays ... But most in the 0-100 GeV range limited by √s

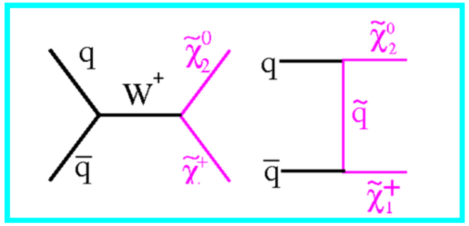
➔ Need LHC to explore the 0.1-1 TeV (weak-scale) range !

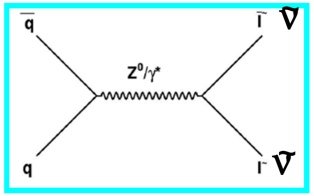
# SUSY production at LHC

❑ R-Parity conserved ➔ sparticles are paired produced at LHC

"Dedicated" searches

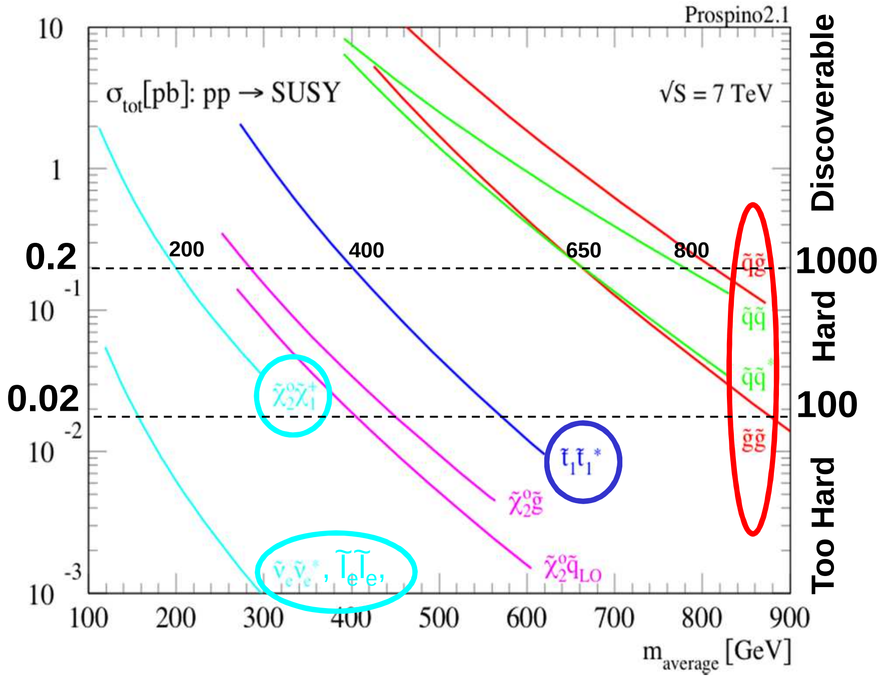


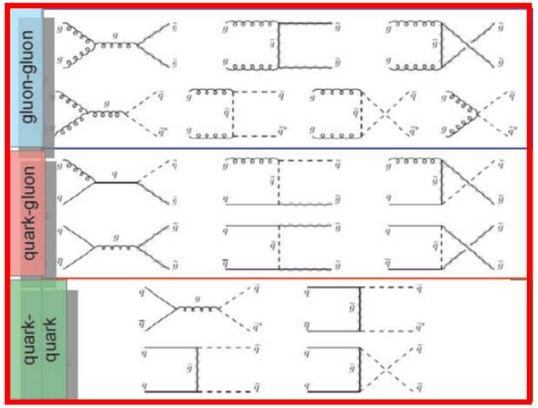


σ(pb)

N(evt) produced in 2011




"Energy frontier/generic" searches



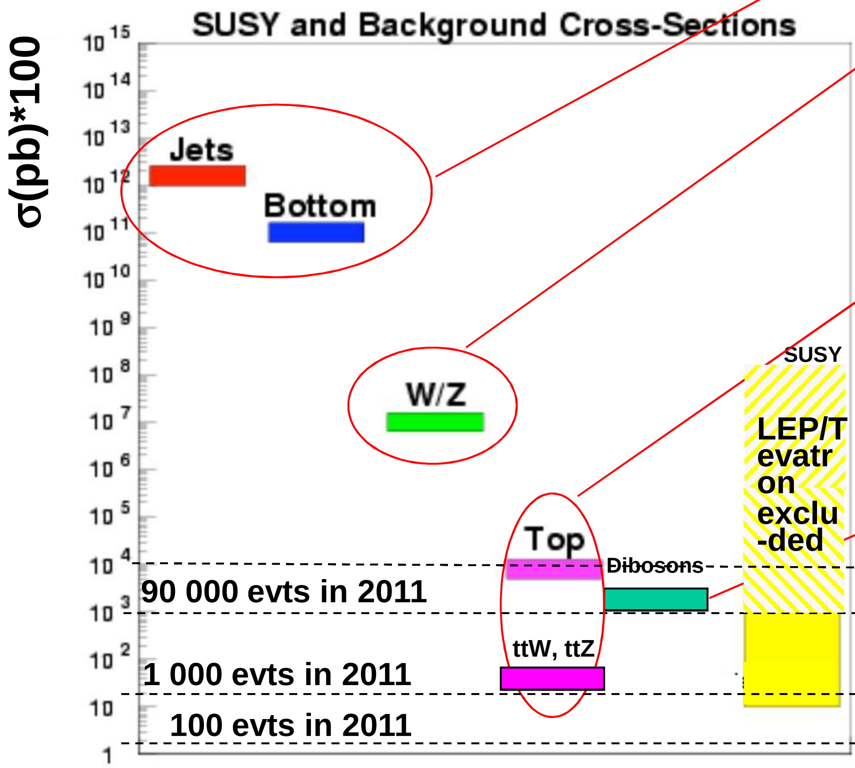

Spin structure of SUSY spectrum (lots of scalars) : lower σ than other BSM models

➔ Searching for SUSY often means building dedicated/refined analyses

# SUSY Challenge at LHC

## ❑ Background !!

*MET=Missing transverse Energy




- ✓Later called «QCD»: **fake MET (low MET** for bb**)**
- ✓W→lν+jets (ISR/FSR): l=**e,μ**, l=τ→**jet**, ν→**MET***
- ✓Z→νν+jets (ISR/FSR): **MET+jets** irreducible
- ✓tt→bWbW→bqqbqq: **jet**s and low **MET** (b-decay)
- ✓tt→bWbW→bqqblν: l=**e,μ**, l=τ→**jet**, ν→**MET**
- ✓tt→bWbW→blνblν: l=**e,μ**, l=τ→**jet**, ν→**MET**
- ✓**tt+jets (ISR,FSR)**
- ✓tt+X with X=bb,Z,W,H, γ : Predicted but not yet discovered!
- ✓Single top: Wt, tb, tbqq
- ✓WW→lνlν, ZZ→llνν, WZ→lνqq: **lept., jet**s, **MET**

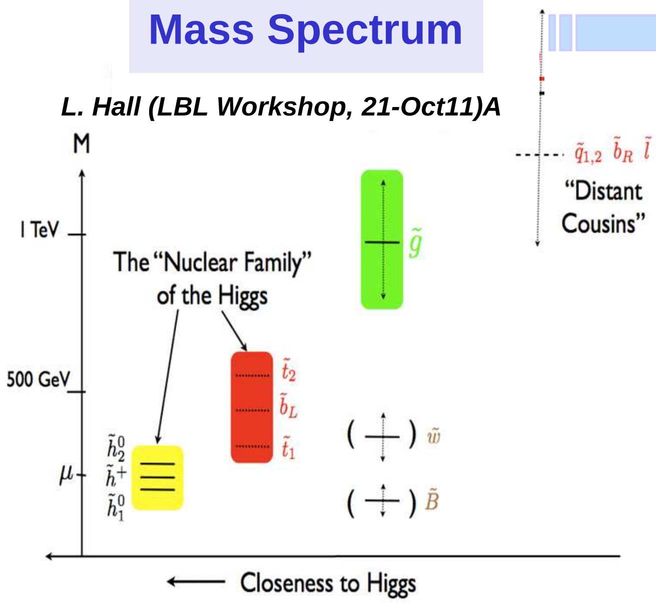
**Excluded by LHC 2010**
m(g,q)~ **500** GeV, m($t_1$)~ **200** GeV, m($\chi_{1,2}$)~ **60** GeV
**Discoverable**
m(g,q)~ **850** GeV, m($t_1$)~ **400** GeV, m($\chi_{1,2}$)~ **200** GeV
**Hard**
m(g,q)~**1300** GeV, m($t_1$)~ **600** GeV, m($\chi_{1,2}$)~ **350** GeV
**Too Hard**

➔ Need to suppress QCD / WZ / top by ~ $10^{10}$ / $10^5$ / $10^2$ + estimate small remaining quantities

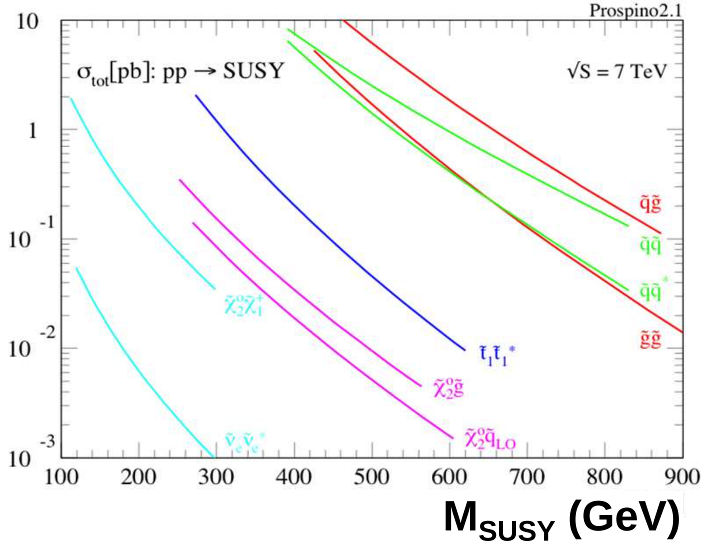
# ATLAS SUSY Search strategy

**Mass Spectrum**

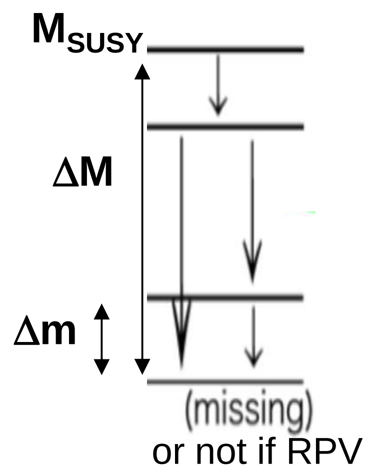
*L. Hall (LBL Workshop, 21-Oct11)A*




**1.Production cross-section**




**2.Decay**




**Phenomelogy** ⟶ **Signature**

1. Strong production (low, high **$\Delta M/M_{SUSY}$**) — Inclusive jets+MET
2. Natural spectrum — Dedicated searches with bjets, multileptons, jet/Z veto
3. Low **$\Delta m$**, tiny RPV, weak coupling to $\tilde{G}$ — Long Lived or meta-stable sparticles
4. 'Sizeable' RPV — Multileptons (inc. tau), No Z, jet resonances, LFV
5. MSSM Extensions? — Scalar Gluon, Dark Matter direct production

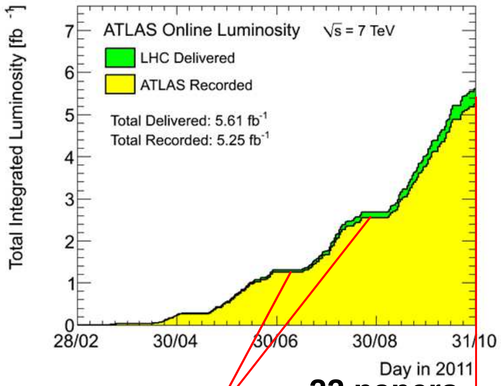
➔ Phenomenology oriented searches

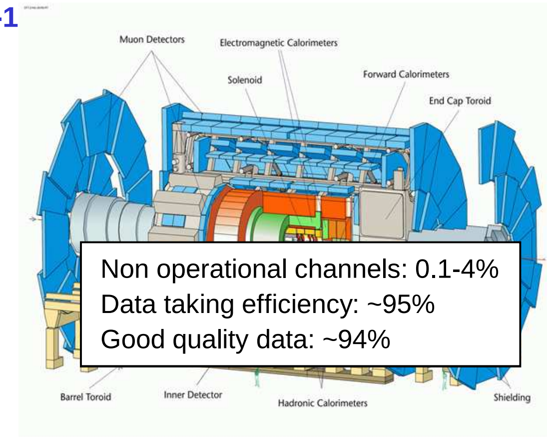
# 2011-2012 ATLAS SUSY searches

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

## ❑ Use the (fantastic) machine and detector to search in every corner

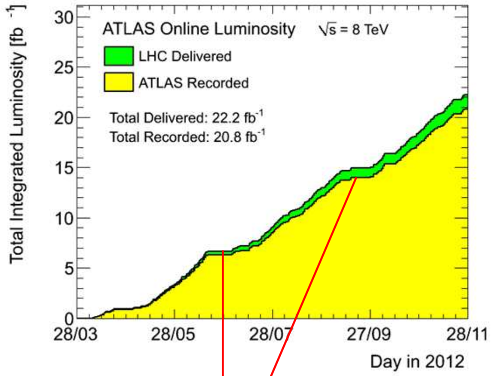
**2011: $L_{int}$=1or 2 or 4.7 fb$^{-1}$**




Non operational channels: 0.1-4%
Data taking efficiency: ~95%
Good quality data: ~94%

**2012: $L_{int}$ =6 or 13 fb$^{-1}$**




### 15 papers

| | | | | | | |
|---|---|---|---|---|---|---|
| Electron-muon continuum [RPV] | 05/2012 | 7 | 2.05 | 1205.0725 | Link (inc. HEPData) | EPJC 72 (2012) 2040 |
| Z->ll + b-jet + jets + Etmiss [Direct Stop Natural GMSB] | 04/2012 | 7 | 2.05 | 1204.6736 | Link (inc. HEPData) | Accepted by PLB |
| =3 leptons + Etmiss [Direct Gauginos] | 04/2012 | 7 | 2.05 | 1204.5638 | Link (inc. HEPData) | PRL 108 (2012) 261804 |
| >=1 tau + jets + Etmiss [GMSB] | 04/2012 | 7 | 2.05 | 1204.3852 | Link | PLB 714 (2012) 197 |
| >=2 taus + jets + Etmiss [GMSB] | 03/2012 | 7 | 2.05 | 1203.6580 | Link (inc. HEPData) | PLB 714 (2012) 180 |
| b-jet(s) + 0-1 lepton + jets + Etmiss [Gluino med. stop/sb.] | 03/2012 | 7 | 2.05 | 1203.6193 | Link | PRD 85 (2012) 112006 |
| 2 same-sign leptons + jets + Etmiss | 03/2012 | 7 | 2.05 | 1203.5763 | Link (inc. HEPData) | PRL 108 (2012) 241802 |
| 2 b-jets + Etmiss [Direct sbottom] | 12/2011 | 7 | 2.05 | 1112.3832 | Link (inc. HEPData) | PRL 108 (2012) 181802 |
| Disappearing track + jets + Etmiss [AMSB Strong Prod.] | 02/2012 | 7 | 1.02 | 1202.4847 | Link | EPJC 72 (2012) 1993 |
| 2 photons + Etmiss [GGM] | 11/2011 | 7 | 1.07 | 1111.4116 | Link | PLB 710 (2012) 519 |
| 2 leptons + jets + Etmiss | 10/2011 | 7 | 1.04 | 1110.6189 | Link (inc. HEPData) | PLB 709 (2012) 137 |
| 0 lepton + >=(6-8) jets + Etmiss | 10/2011 | 7 | 1.34 | 1110.2299 | Link (inc. HEPData) | JHEP 11 (2011) 99 |
| 1 lepton + jets + Etmiss | 09/2011 | 7 | 1.04 | 1109.6606 | Link (inc. HEPData) | PRD 85 (2012) 012006 |
| 0 lepton + >=(2-4) jets + Etmiss | 09/2011 | 7 | 1.04 | 1109.6572 | Link (inc. HEPData) | PLB 710 (2012) 67 |
| Electron-muon resonance [RPV] | 09/2011 | 7 | 1.07 | 1109.3089 | Link (inc. HEPData) | EPJC 71 (2011) 1809 |

### 6 CONF Notes

| Short Title of the CONF note | Date | √s (TeV) | L (fb$^{-1}$) | Document | Plots |
|---|---|---|---|---|---|
| Add. >=4 leptons + Etmiss Interpretation (RPV) | 03/2012 | 7 | 2.05 | ATLAS-CONF-2012-035 | Link (inc. HEPData) |
| Long lived Particle (Pixel-like) | 03/2012 | 7 | 2.05 | ATLAS-CONF-2012-022 | Link |
| >=4 leptons + Etmiss | 01/2012 | 7 | 2.05 | ATLAS-CONF-2012-001 | Link (inc. HEPData) |
| Z->ll + jets + Etmiss (GGM) NEW | 04/2012 | 7 | 1.04 | ATLAS-CONF-2012-047 | Link |
| Add. 2 leptons + jets + Etmiss interpretation (GMSB) | 11/2011 | 7 | 1.04 | ATLAS-CONF-2011-156 | Link |
| Add. 0 lepton + jets + Etmiss interpretation | 11/2011 | 7 | 1.04 | ATLAS-CONF-2011-155 | Link (inc. HEPData) |

### 22 papers

| Short Title of the Paper | Date | √s (TeV) | L (fb$^{-1}$) | Document | Plots+Aux. Material | Journal |
|---|---|---|---|---|---|---|
| Long-lived particles [R-hadrons, slepton] NEW | 11/2012 | 7 | 4.7 | 1211.1597 | Link | Submitted to PLB |
| 1 photon + >=1 b-jet + Etmiss [GGM, higgsino NLSP] NEW | 11/2012 | 7 | 4.7 | 1211.1167 | Link | Submitted to PLB |
| Muon + displaced vertex [RPV] NEW | 10/2012 | 7 | 4.7 | 1210.7451 | Link | Submitted to PLB |
| Pair of 2-jet resonance [N=1/2 scalar gluon] NEW | 10/2012 | 7 | 4.6 | 1210.4826 | Link | Submitted to EPJC |
| Pair of 3-jet resonance [RPV] NEW | 10/2012 | 7 | 4.6 | 1210.4813 | Link | Submitted to JHEP |
| >=4 leptons + Etmiss [RPV] NEW | 10/2012 | 7 | 4.7 | 1210.4457 | Link | Accepted by JHEP |
| Monojet + Etmiss [WIMP] NEW | 10/2012 | 7 | 4.7 | 1210.4491 | Link | Submitted to JHEP |
| Disappearing track + jets + Etmiss [Direct long-lived charginos - AMSB] NEW | 10/2012 | 7 | 4.7 | 1210.2852 | Link | Submitted to JHEP |
| 1-2 taus + 0-1 leptons + jets + Etmiss [GMSB] NEW | 10/2012 | 7 | 4.7 | 1210.1314 | Link | EPJC 72 (2012) 2215 |
| Monophoton [ADD, WIMP] | 09/2012 | 7 | 4.7 | 1209.4625 | Link | Submitted to PRL |
| 2 leptons + jets + Etmiss [Medium stop] | 09/2012 | 7 | 4.7 | 1209.4186 | Link | Accepted by JHEP |
| 1-2 b-jets + 1-2 leptons + jets + Etmiss [Light Stop] | 09/2012 | 7 | 4.7 | 1209.2102 | Link | Submitted to PLB |
| 2 photons + Etmiss [GGM, bino NLSP] | 09/2012 | 7 | 4.7 | 1209.0753 | Link | Accepted by PLB |
| 1-2 leptons + >=2-4 jets + Etmiss | 08/2012 | 7 | 4.7 | 1208.4688 | Link | Accepted by PRD |
| 2 leptons + >=1 jet + Etmiss [Very light stop] | 08/2012 | 7 | 4.7 | 1208.4305 | Link (inc. HEPData) | Accepted by EPJC |
| 3 leptons + Etmiss [Direct gauginos] | 08/2012 | 7 | 4.7 | 1208.3144 | Link (inc. HEPData) | Accepted by PLB |
| 2 leptons + Etmiss [Direct gauginos/sleptons] | 08/2012 | 7 | 4.7 | 1208.2884 | Link | Accepted by PLB |
| 1 lepton + >=4 jets (>=1 b-jet) + Etmiss [Heavy stop] | 08/2012 | 7 | 4.7 | 1208.2590 | Link (inc. HEPData) | PRL 109 (2012) 211803 |
| 0 lepton + 1-2 b-jet + 5-4 jets + Etmiss [Heavy stop] | 08/2012 | 7 | 4.7 | 1208.1447 | Link | Accepted by PRL |
| 0 lepton + >=2-6 jets + Etmiss | 08/2012 | 7 | 4.7 | 1208.0949 | Link (inc. HEPData) | Submitted to PRD |
| 0 lepton + >=3 b-jets + >=(1-3) jets + Etmiss [Gluino med. stop/sb.] | 07/2012 | 7 | 4.7 | 1207.4686 | Link | Accepted by EPJC |
| 0 lepton + >=(6-9) jets + Etmiss | 06/2012 | 7 | 4.7 | 1206.1760 | Link (inc. HEPData) | JHEP 1207 (2012) 167 |

### 6 CONF Notes

| Short Title of the Conf. note | Date | √s (TeV) | L (fb$^{-1}$) | Document | Plots |
|---|---|---|---|---|---|
| 1 photon + 1 lepton + Etmiss [GGM, wino NLSP] NEW | 10/2012 | 7 | 4.8 | ATLAS-CONF-2012-144 | Link |
| 1 lepton + >=7 jets + Etmiss | 10/2012 | 7 | 4.7 | ATLAS-CONF-2012-140 | Link |
| 3 leptons + jets + Etmiss [3rd gen. squarks] | 08/2012 | 7 | 4.7 | ATLAS-CONF-2012-108 | Link |
| 2 b-jets + Etmiss [Direct sbottom] | 08/2012 | 7 | 4.7 | ATLAS-CONF-2012-106 | Link |
| General new phenomena search | 08/2012 | 7 | 4.7 | ATLAS-CONF-2012-107 | Link |
| Disappearing track + jets + Etmiss [AMSB Strong Prod.] | 03/2012 | 7 | 4.7 | ATLAS-CONF-2012-034 | Link |

### 10 CONF Notes

| Short Title of the CONF note | Date | √s (TeV) | L (fb$^{-1}$) | Document | Plots |
|---|---|---|---|---|---|
| 3 leptons + Etmiss [Direct gauginos] NEW | 11/2012 | 8 | 13.0 | ATLAS-CONF-2012-154 | Link |
| 4 leptons + Etmiss [RPV] NEW | 11/2012 | 8 | 13.0 | ATLAS-CONF-2012-153 | Link |
| 0 lepton + >=3 b-jets + Etmiss [3rd gen. squarks] NEW | 11/2012 | 8 | 12.8 | ATLAS-CONF-2012-145 | Link |
| 3 leptons + jets + Etmiss [3rd gen. squarks] NEW | 11/2012 | 8 | 13.0 | ATLAS-CONF-2012-151 | Link |
| Monojet + Etmiss [WIMP, gravitino prod.] NEW | 11/2012 | 8 | 10.5 | ATLAS-CONF-2012-147 | Link |
| Z + jets + Etmiss [GGM, higgsino NLSP] NEW | 11/2012 | 8 | 5.8 | ATLAS-CONF-2012-152 | Link |
| 0 leptons + >=2-6 jets + Etmiss | 08/2012 | 8 | 5.8 | ATLAS-CONF-2012-109 | Link |
| 0 leptons + >=6-9 jets + Etmiss | 08/2012 | 8 | 5.8 | ATLAS-CONF-2012-103 | Link |
| 1 lepton + >=4 jets + Etmiss | 08/2012 | 8 | 5.8 | ATLAS-CONF-2012-104 | Link |
| 2 same-sign leptons + >=4 jets + Etmiss | 08/2012 | 8 | 5.8 | ATLAS-CONF-2012-105 | Link |

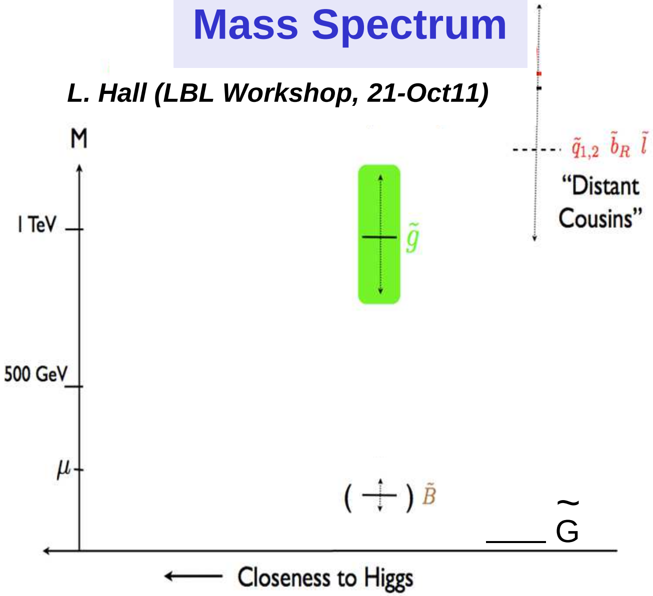
7 TeV 8 TeV

➔ Today show highlights of the **7 TeV** & **8 TeV** results

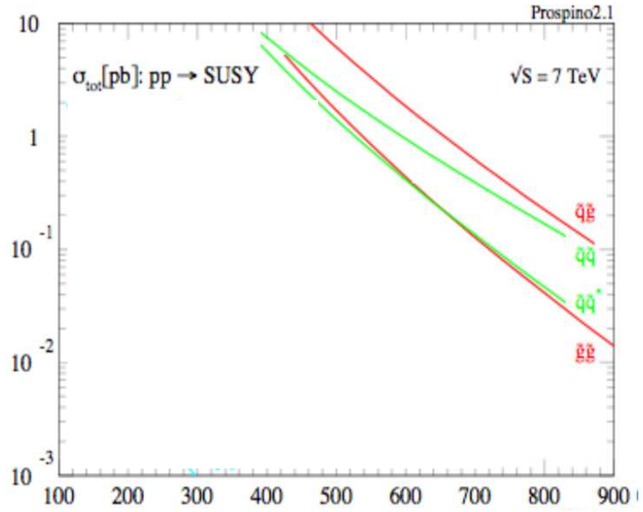
# Inclusive searches

**Mass Spectrum**

*L. Hall (LBL Workshop, 21-Oct11)*

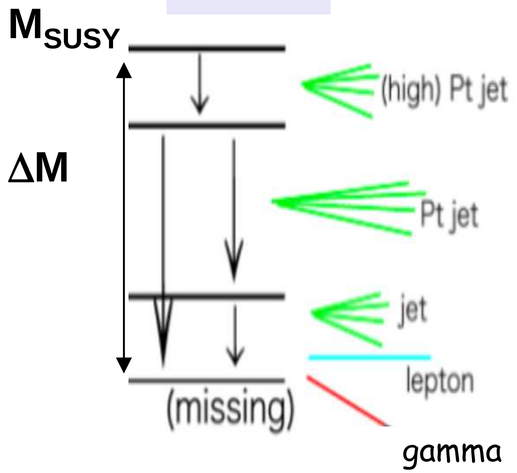



**Production**




$M_{SUSY}$ (GeV)

**Decay**




**MET ~ ΔM**
**$H_T = \Sigma\, p_T$ (jet) [+ $p_T$ (l,γ)] ~ ΔM**
**$M_{Eff}$=MET+$H_T$ ~ 2 $M_{SUSY}$**

1. Strong production (low, high **$\Delta M/M_{SUSY}$**) ➔ **Inclusive jets+MET**

**Massive LSP=$\tilde{\chi}_1^0$**

- **squarks/gluino cascade**: **0** lepton + **1-9** jets + MET
- **squark/gluino cascade + leptonic gaugino/slepton decay**: 1lepton (e μ) + jets +MET
- **gluino cascade + leptonic gaugino/slepton decay**: 2leptons (e μ) same sign + jets +MET

**~Massless LSP=$\tilde{G}$**

- **squark/gluino cascade in GMSB / GGM** : (1)2 leptons [e,μ,τ] + jets +MET
  γγ+MET, γ+l+MET, γ+b+MET, Z+MET

# Inclusive searches (1)

ATLAS-CONF-2012-109

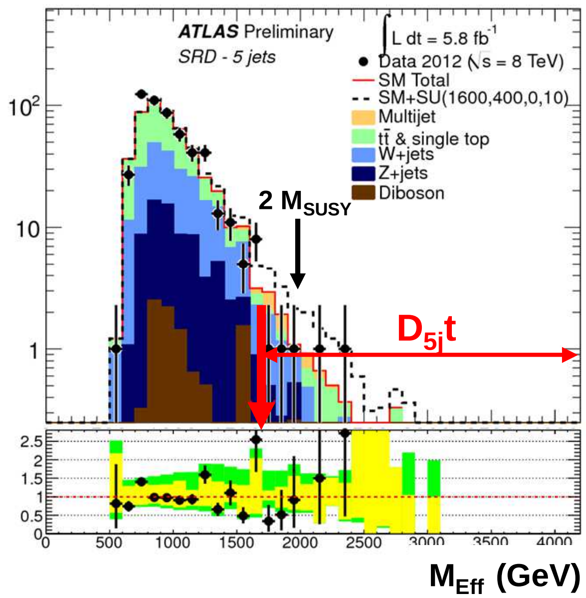
8 TeV

## ❑ 'Standard' 0lepton + jets + MET searches : Most inclusive !

- 0lepton : highest branching ratios generally in $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ and $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$
- Design 12 (inclusive) signal region to cover most of the phase space

| | Requirement | Channel A 2-jets | Channel B 3-jets | Channel C 4-jets | Channel D 5-jets | Channel E 6-jets |
|---|---|---|---|---|---|---|
| Trigger | $E_T^{miss}$[GeV] > | 160 | | | | |
| Trigger | $p_T(j_1)$ [GeV] > | 130 | | | | |
| Pile-up | $p_T(j_2)$ [GeV] > | 60 | | | | |
| Pile-up | $p_T(j_3)$ [GeV] > | – | 60 | 60 | 60 | 60 |
| Pile-up | $p_T(j_4)$ [GeV] > | – | – | 60 | 60 | 60 |
| Pile-up | $p_T(j_5)$ [GeV] > | – | – | – | 60 | 60 |
| Pile-up | $p_T(j_6)$ [GeV] > | – | – | – | – | 60 |
| QCD rejection | $\Delta\phi(\text{jet}, \mathbf{E}_T^{miss})_{min}$ [rad] > | 0.4 ($i = \{1, 2, (3)\}$) | | 0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T > 40$ GeV jets) | | |
| QCD rejection | $E_T^{miss}/m_{eff}(Nj)$ > | 0.3/0.4/0.4 (2j) | 0.25/0.3/– (3j) | 0.25/0.3/0.3 (4j) | 0.15 (5j) | 0.15/0.25/0.3 (6j) |
| $M_{Eff}$ | $m_{eff}$(incl.) [GeV] > | 1900/1300/1000 | 1900/1300/– | 1900/1300/1000 | 1700/–/– | 1400/1300/1000 |

SUSY model: $m_{\tilde{g}/\tilde{q}}$ = 1.0/1.4 TeV

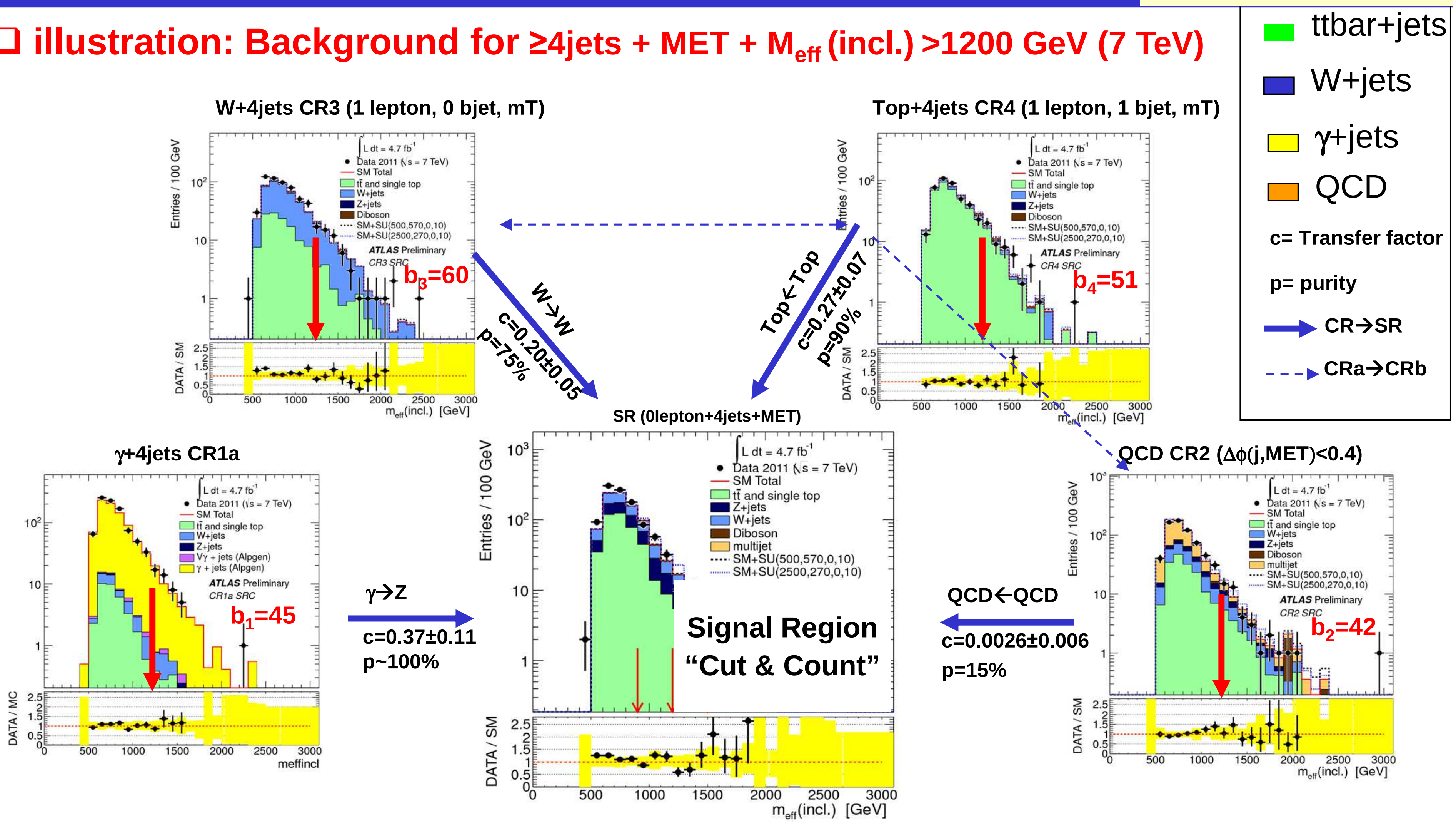



➔ 5 Tight (t) and 7 Medium/Loose (l, m) signal regions

# Inclusive searches (2)

ATLAS-CONF-2012-033

- illustration: Background for ≥4jets + MET + $M_{eff}$ (incl.) >1200 GeV (7 TeV)




➔ Errors contains exp. (Jet Energy scale, btagging) and theo. (PDF, scale) syst.

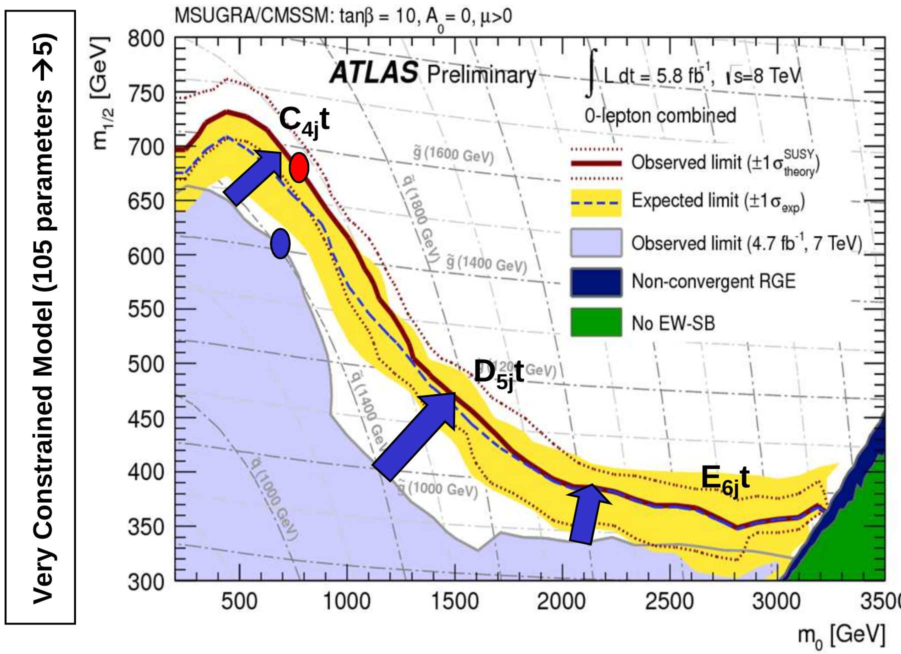
# Inclusive searches (3)

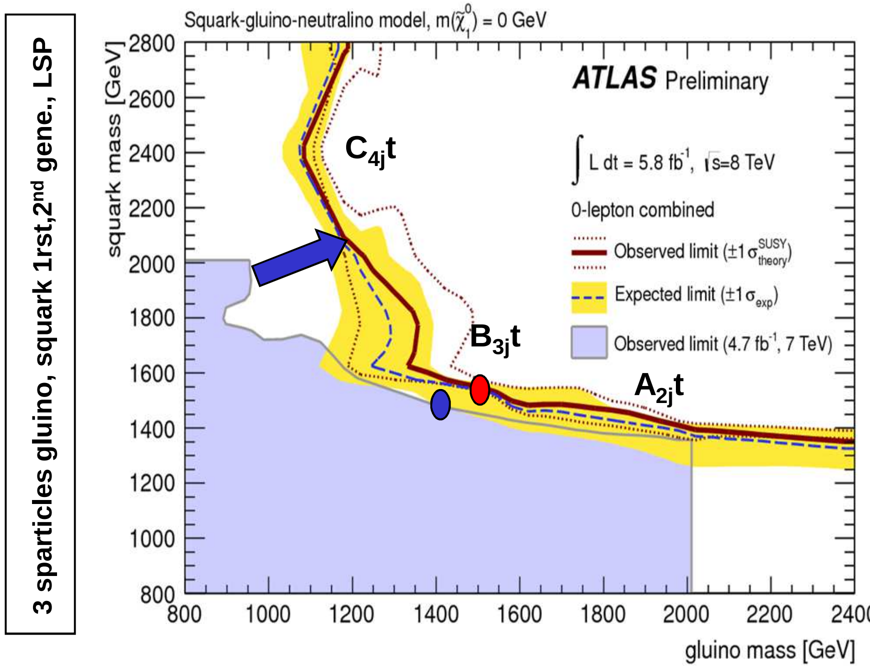
ATLAS-CONF-2012-109

## ❑ Interpretations for high $M_{SUSY}$, large $\Delta M/M_{SUSY}$

8 TeV

- As no excess, set limits by choosing the best expected signal regions
- Governed by tight signal regions (At, Bt, …)




➔ For m(squarks)=m(gluinos), exclude below 1.5 TeV

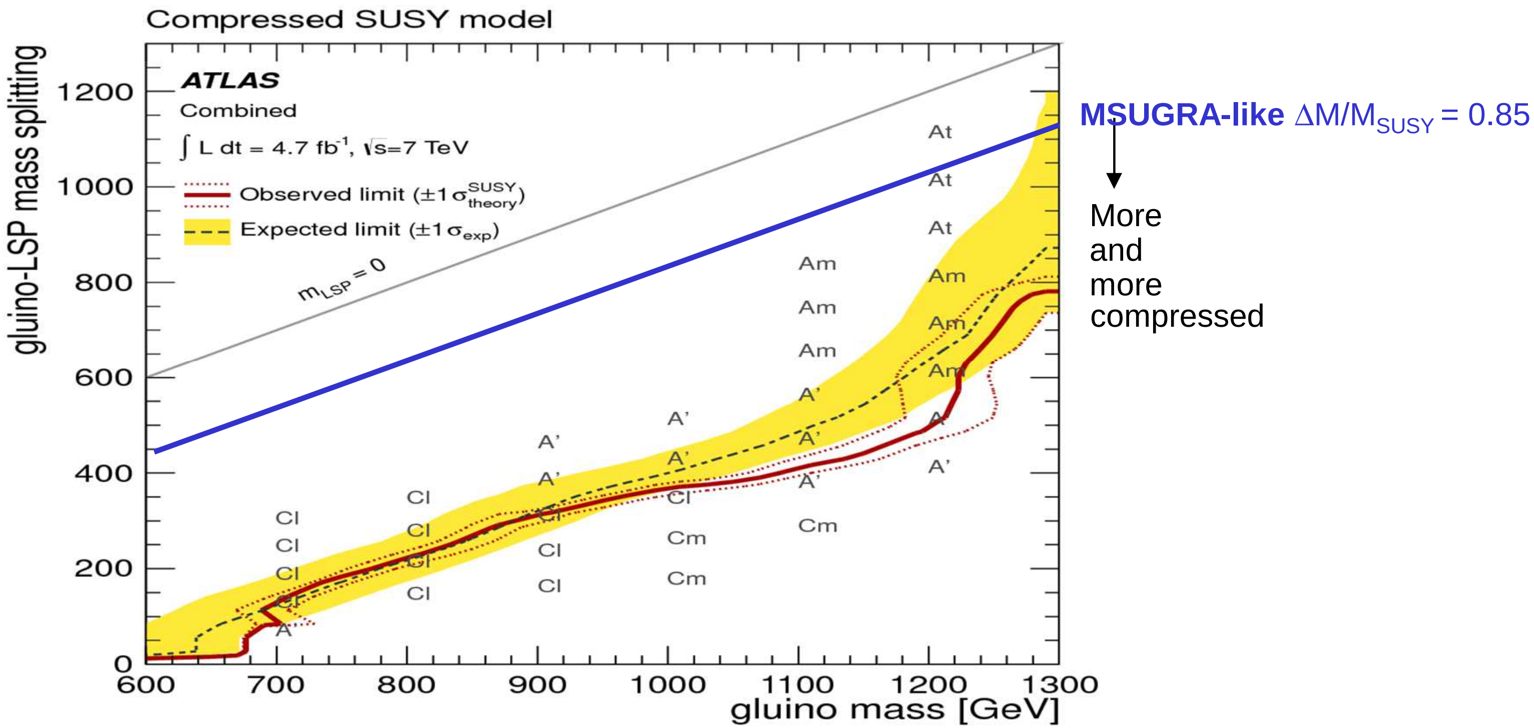
# Inclusive searches (4)

arXiv:1208.0949

## ❑ Interpretations for lower $\Delta M/M_{SUSY}$ ('compressed spectra')

7 TeV

- Models with compressed MSUGRA scenarios $\Delta M/M_{SUSY}$ from 0.85 to 0.15 PRD84 (2011) 015004
- Best expected are Medium (m) and Loose (l) signal regions for $\Delta M/M_{SUSY}$ low




➔ Gain in sensitivity in the compressed spectra for m(gluino)<1.2 TeV

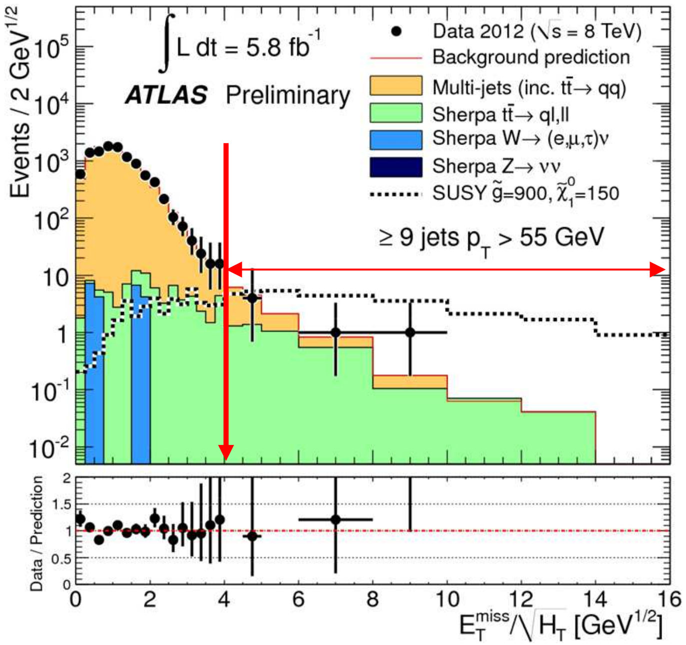
# Inclusive searches (5)

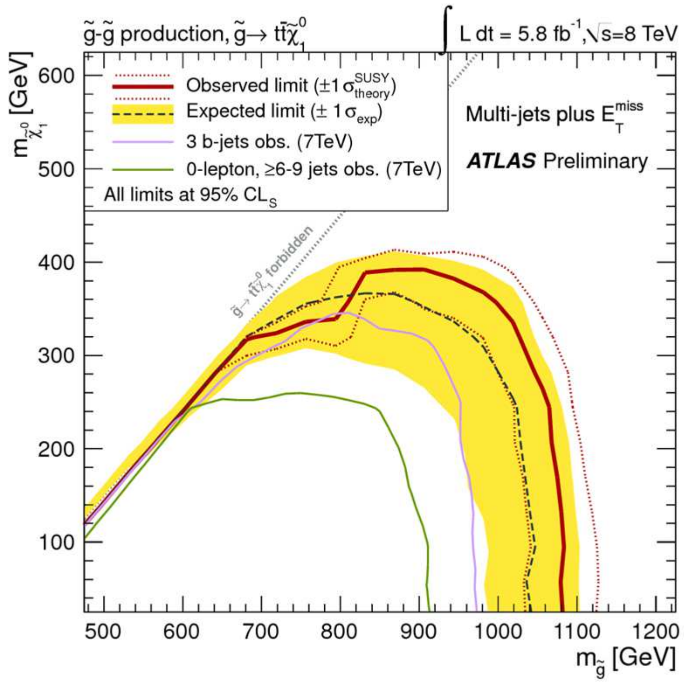
ATLAS-CONF-2012-103

## ❑ What if trigger is ampering our SUSY signal ?

8 TeV

- Multijet trigger, look at higher jet multiplicities (6-9 jets) & cuts on MET/$\sqrt{H_T}$
- Very sensitive to long decay chain: $\tilde{g} \rightarrow qq\tilde{\chi}_1^{+/-} \rightarrow qqqq\tilde{\chi}_1^0$, $\tilde{g} \rightarrow tt\tilde{\chi}_1^0 \rightarrow qqqqqq\tilde{\chi}_1^0$
- Change background composition: Multijets, ttbar all hadronic dominates




➔ Small event overlap wrt standard 0lepton+jets+MET searches

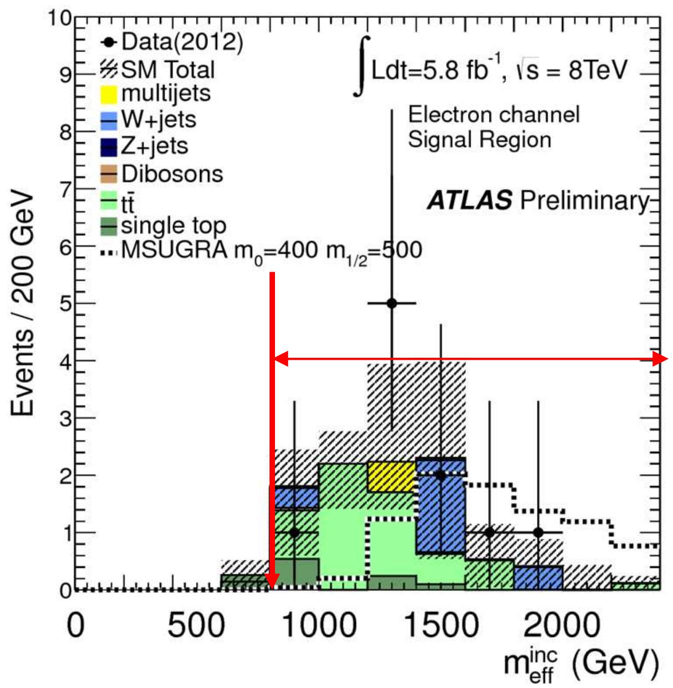
# Inclusive searches (6)

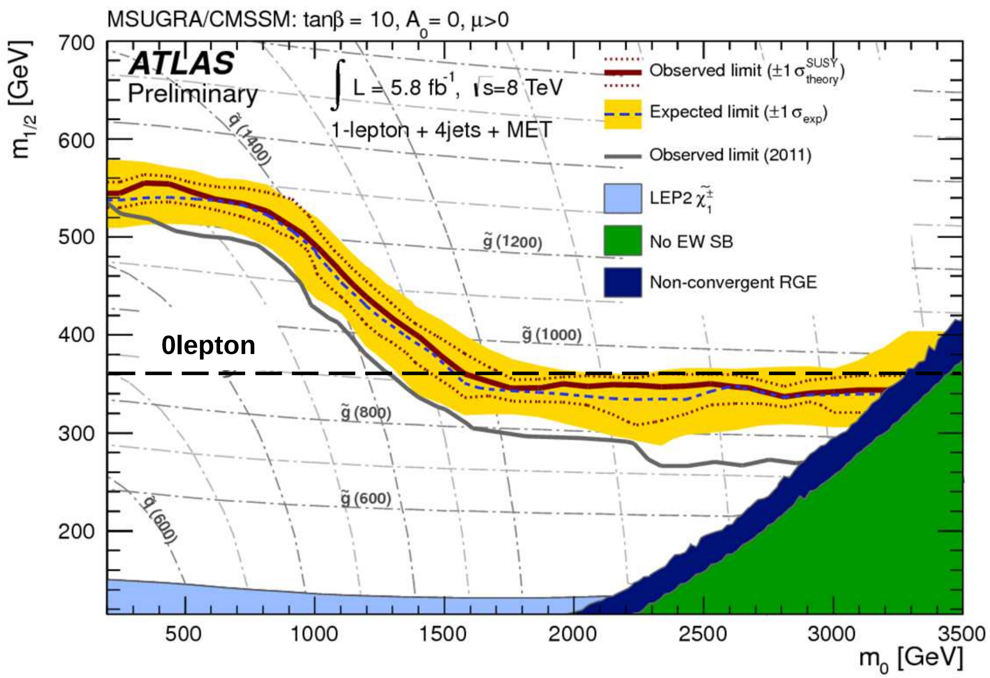
ATLAS-CONF-2012-104

## ❑ What if 'one' lepton (e,μ) is present + ≥4jets + MET ?

8 TeV

- Generate high $p_T$ lepton when $\tilde{g} \rightarrow qq\tilde{\chi}_1^{+/-} \rightarrow qqW(l\nu)\tilde{\chi}_1^0$ or intermediate slepton
  - ✓ Single lepton trigger is sufficient
  - ✓ Lower QCD multi-jet background: can remove Δϕ(j,MET), and relax pT(jets)




➔ Competitive at high $m_0$ where gluino production dominates

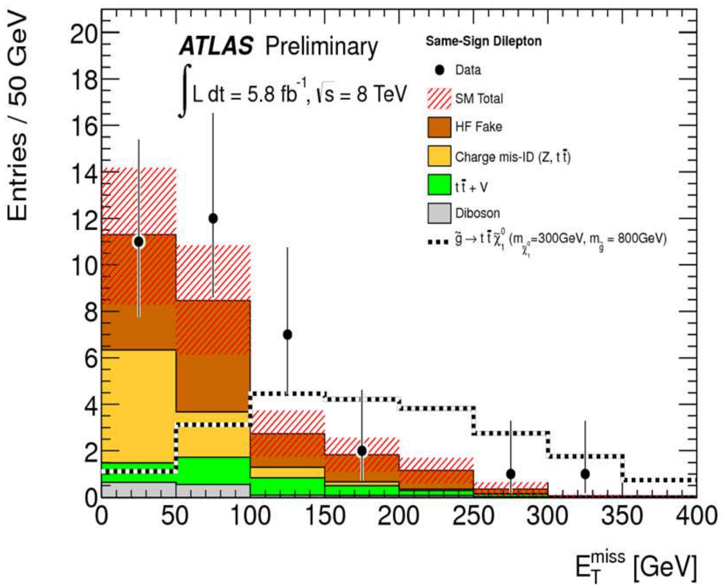
# Inclusive searches (7)

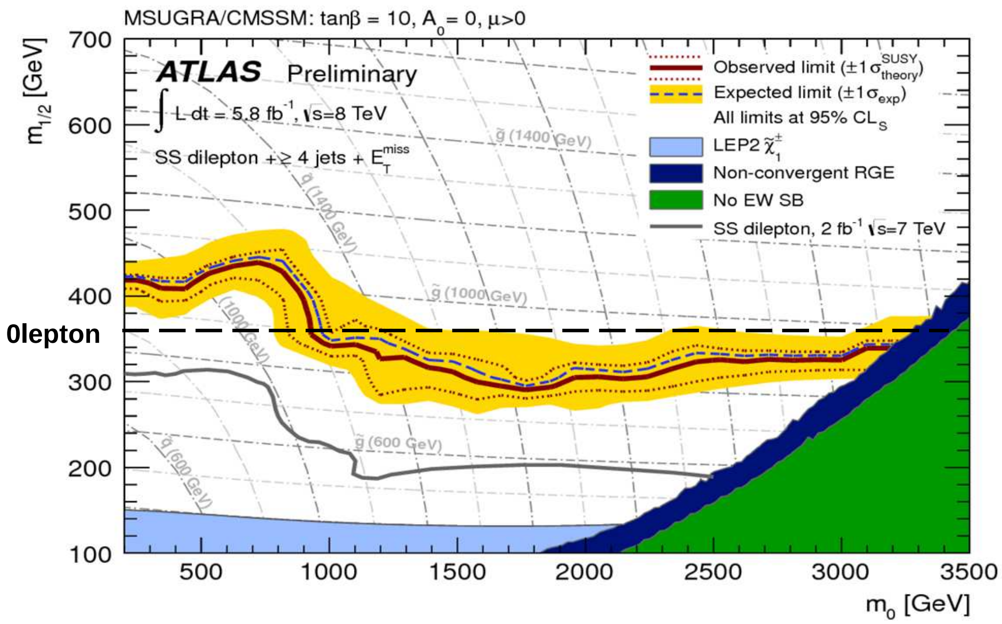
ATLAS-CONF-2012-105

## ❑ What if ‘two’ leptons with same sign (e,μ) + ≥4 jets +MET ?

8 TeV

- In MSSM, gluino are Majorana particles: gives equally $\tilde{q}$ and anti-$\tilde{q}$
  - ➔ same sign leptons from the two legs in ½ of the case + jets +MET
- SM killer which compensates for low branching ratios ➔ background=instrumental & tt+V




➔ Competitive at high $m_0$ where gluino production dominates

# Inclusive searches (8)

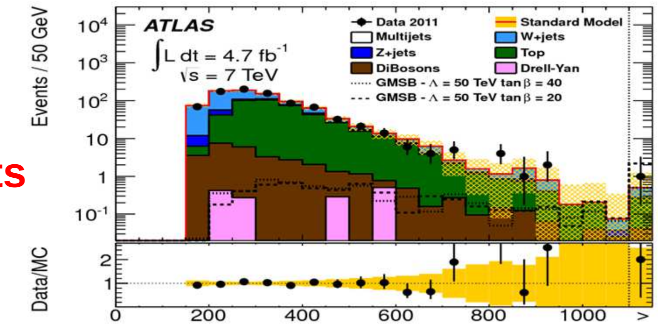
arXiv:1210.1314

arXiv:1208.4688

## ❑ What if 2 opp. Sign lepton (e, $\mu$, $\tau_{had}$) + jets +MET ?

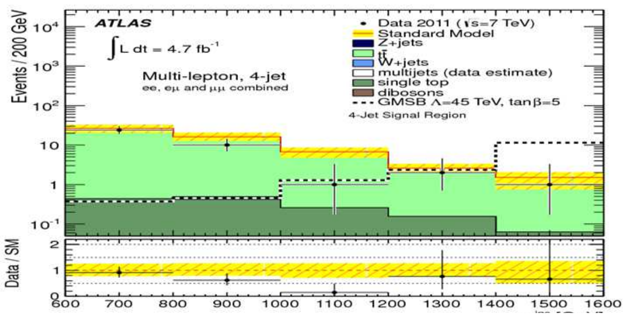
- GMSB: LSP is the gravitino and NLSP determines the event topology
  - ➔ Can enhance the number of taus if stau NLSP* and other leptons if selectron/smuon NLSP
- 6 exclusive channels: e-e, e-$\mu$, $\mu$-$\mu$, =1$\tau_{had}$, ≥2 $\tau_{had}$, e/$\mu$+$\tau_{had}$ + jets +MET

$\tau$+$\mu$ +jets

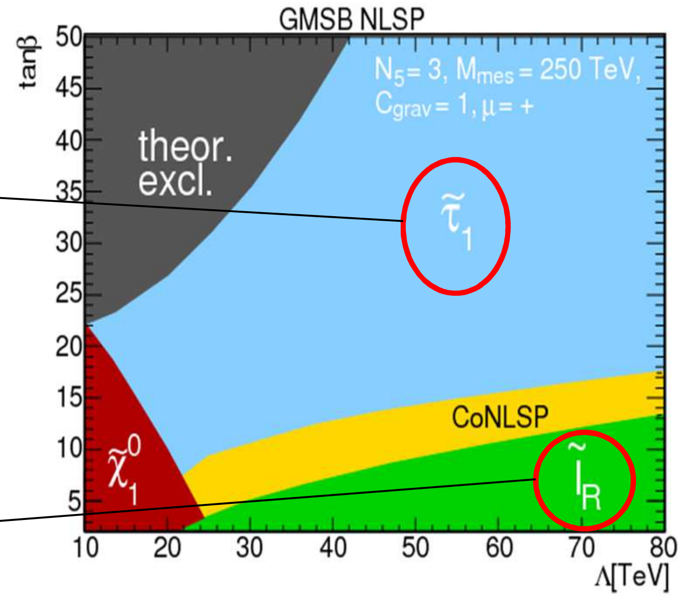



$M_{Eff}$ (GeV)

2l + 4jets




$M_{Eff}$ (GeV)




* Stau can be also be light if large mixing

# Inclusive searches (9)

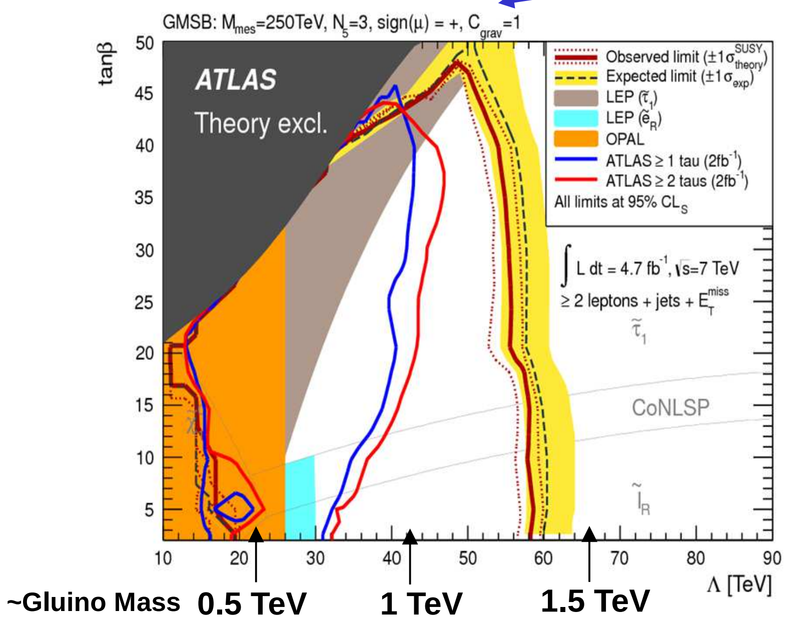
arXiv:1210.1314

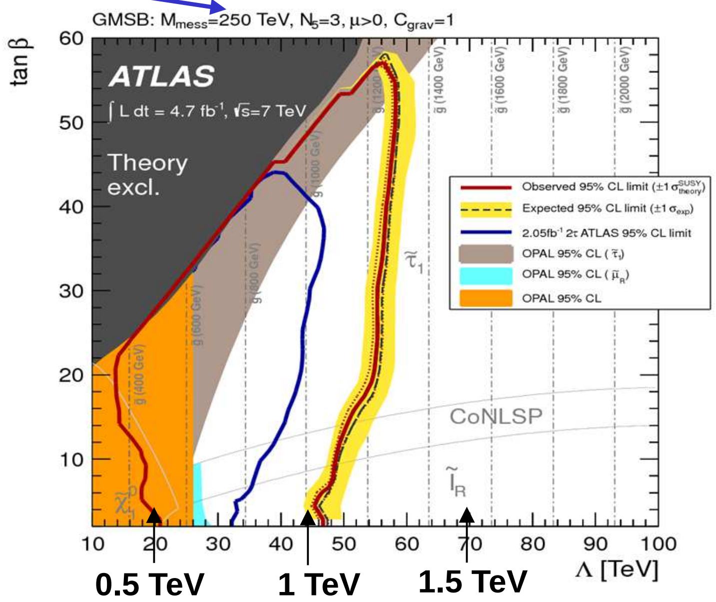
arXiv:1208.4688

7 TeV 7 TeV

## ❑ What if 2 opp. Sign lepton (e, μ, $\tau_{had}$) + jets +MET ?

- GMSB: LSP is the gravitino and NLSP determines the event topology
  - ➔ Can enhance the number of taus if stau NLSP and other leptons if selectron/smuon NLSP
  - ➔ Stau can be also be light if large mixing
- 6 exclusive channels: e-e, e-μ, μ-μ, =1$\tau_{had}$, ≥2 $\tau_{had}$, e/μ+$\tau_{had}$ + jets +MET




➔ Sensitive to gluino masses up to ~ 1.3 TeV

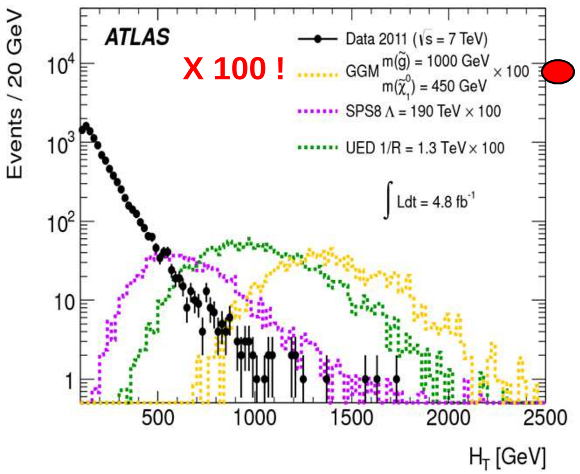
# Inclusive searches (10)

arXiv:1209.0783

## ❑ What if 2 photons + jets + MET ?

- GGM(~GMSB): Enhance di-photon production if $\chi_1^0$-bino like
- Experimental Challenge : determine fake $\gamma$ and tail at high MET
- 3 variables MET, $H_T$ and $\Delta\phi$ ($\gamma$, MET) to increase sensitivity

**After 2 $\gamma$ selection**




**Selection (SRA/B)**

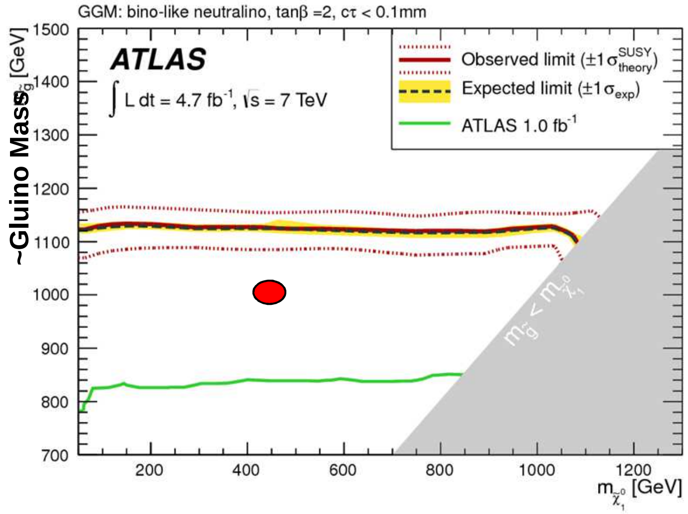
- 2 $\gamma$ pT> 50 GeV
- MET>200/100 GeV
- $H_T$>600/1100 GeV
- $\Delta\phi$($\gamma$,MET)>0.5/0

**Background**

$N_B$=0.1±0.03(stat)±0.07(syst)
Syst dominated by fake $\gamma$

**Signal**

Syst is 10%/30 % for exp/theo around the limit




➔ Also quite strong in the NLSP bino case ($M_{\tilde{g}}$> 1.1 TeV)

# Inclusive searches (11)

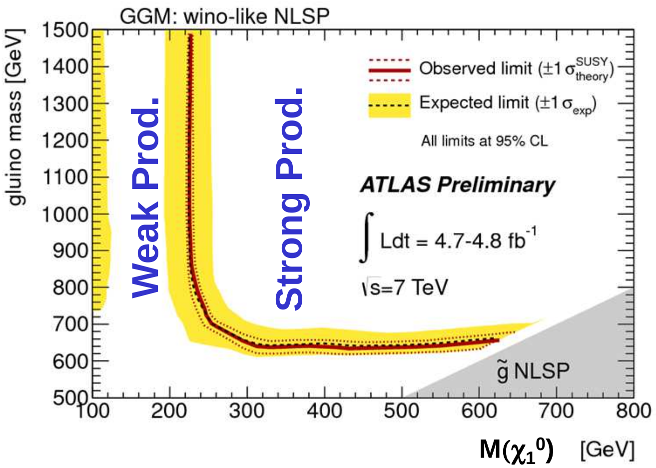
ATLAS-CONF-2012-144, arXiv:1211.1167, ATLAS-CONF-2012-152

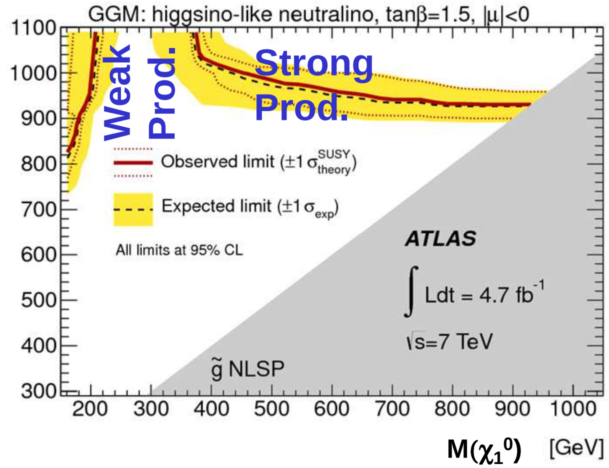
## ❑ What if Higgs or Z in the cascade ?

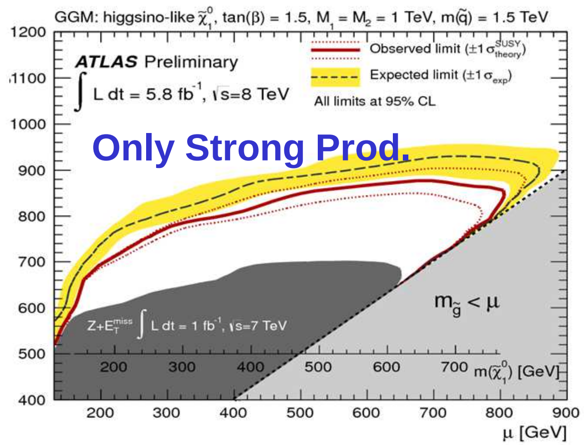
7 TeV 7 TeV 8 TeV

- GGM: enhance Higgs/Z final states if $\chi_1^0$-wino or Higgsino
- Can be produced via weak or strong production

| $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ Wino-like | $\tilde{\chi}_1^0$ Higgsino-like | $\tilde{\chi}_1^0$ Higgsino-like |
|---|---|---|
| $\tilde{\chi}_1^\pm \rightarrow W(\rightarrow l\nu)\,\tilde{G}$, $\tilde{\chi}_1^0 \rightarrow \gamma(Z)\,\tilde{G}$ | $\tilde{\chi}_1^0 \rightarrow \gamma/H(\rightarrow bb)\,\tilde{G}$ | $\tilde{\chi}_1^0 \rightarrow Z(\rightarrow ll)/H\,\tilde{G}$ |
| **1γ + 1lepton + Zveto + MET** | **1γ + ≥1b + lepton veto +MET** | **Z + jets + MET** |




➔ A wide range of signature gives $M_{\tilde{g}}$ > 0.6 TeV)

# Natural SUSY searches

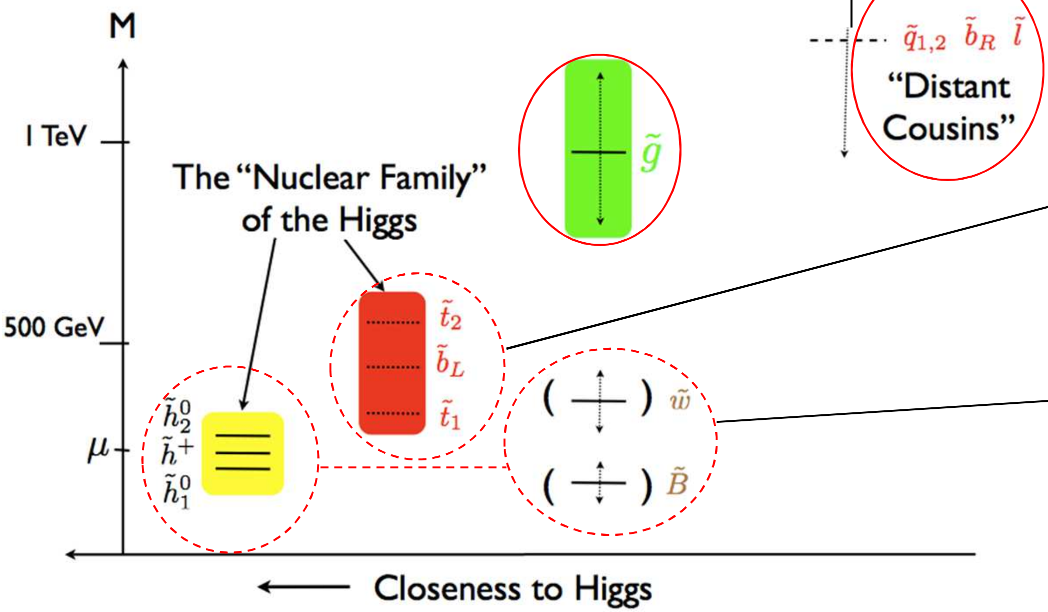
## ❑ "Natural" SUSY ➔ Dedicated searches

~~Fee~~ See Inclusive searches

- SUSY spectrum needed to stabilize the Higgs Mass w/o fine tuning

**Theory view**

*L. Hall (LBL Workshop, 21-Oct11)*




**Light squarks, sleptons :**«decoupled»

~~*Direct production*: jets + MET (+leptons)~~

**Gluino :**

~~*Direct production*: jets + MET (+leptons)~~
~~but cross-section may be low~~

**3rd generation:**

*Direct production*: bs, Ws, ts + MET

*Gluino mediated*: same + jets

**EWK-inos=Gauginos ($\tilde{\chi}^0_1$=LSP):**

*Direct production*: leptons, MET, Jet veto

~~*Gluino mediated*: leptons, jets, MET~~

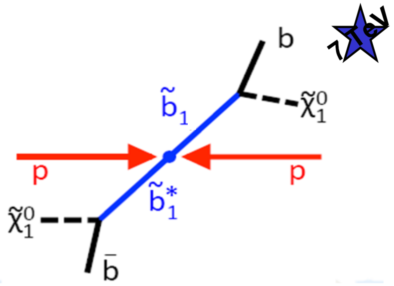
➔ Final results at $\sqrt{s}$=7 TeV, first results with 8fb$^{-1}$

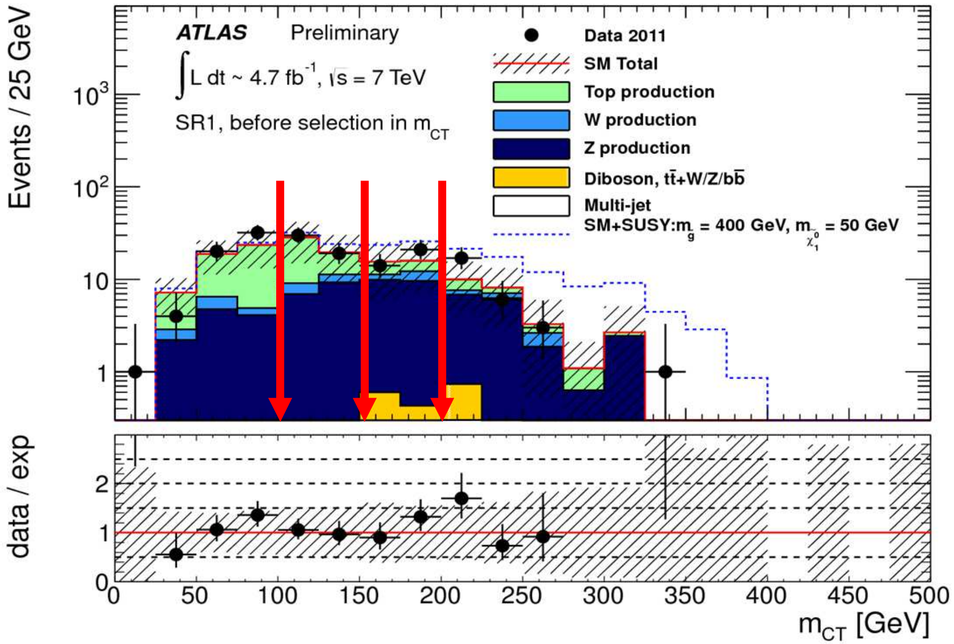
# Natural SUSY searches (1)

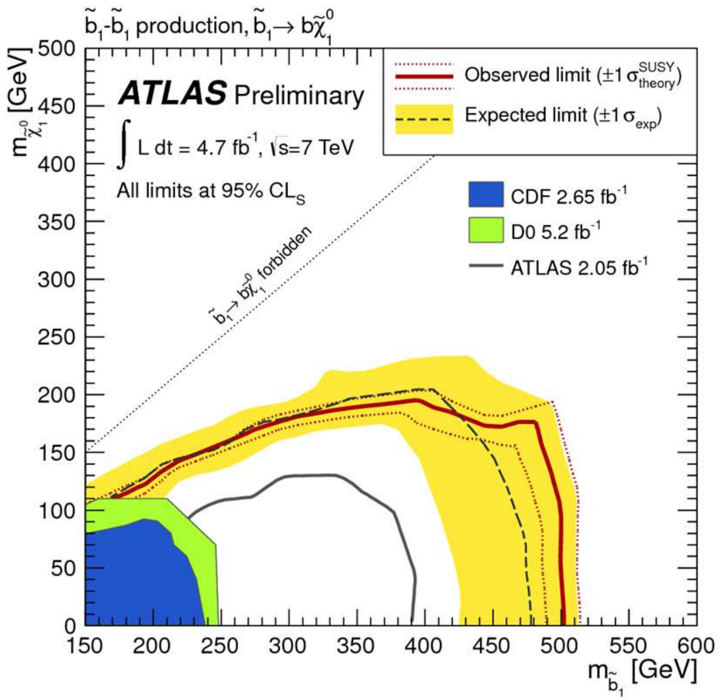
ATLAS-CONF-2012-106

## ❑ Final results on Direct sbottom at $\sqrt{s}$=7 TeV, 5 fb$^{-1}$

- Exploit fully 2 body-decay topology
  - ✓ $m_{CT}$ as discriminating variable, cut near the end-point
- **3** signal regions: exclusive 2 b-jets, 2b-jets+ISR




➔ Sensitive to $m_{\tilde{b}}$<500 GeV (as the direct stop)

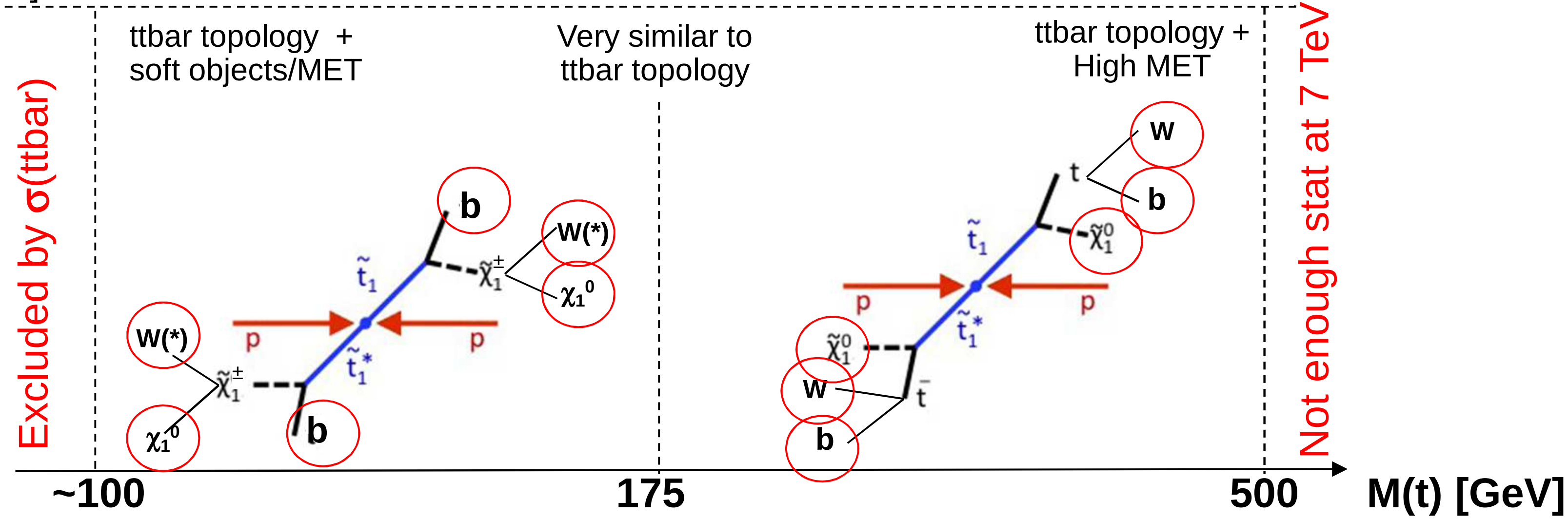
# Natural SUSY searches (2)

## ❑ A bit more complicated case: direct stop

- At √s=7TeV, σ(ttbar)= 177±11 pb is measured by ATLAS
  - ➔ Exclude m(stop)<100 GeV

| 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 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |

| | ~100 | 175 | 500 |
|---|---|---|---|
| $\sigma(\tilde{t}\tilde{t})$[pb] | **300±50** | **30±5** | **0.05±0.01** |
| N[5fb$^{-1}$] | **1.500.000** | **150.000** | **250** |




➔ Most promising final states 2b + 2(4)jets + 0(1)lepton + MET

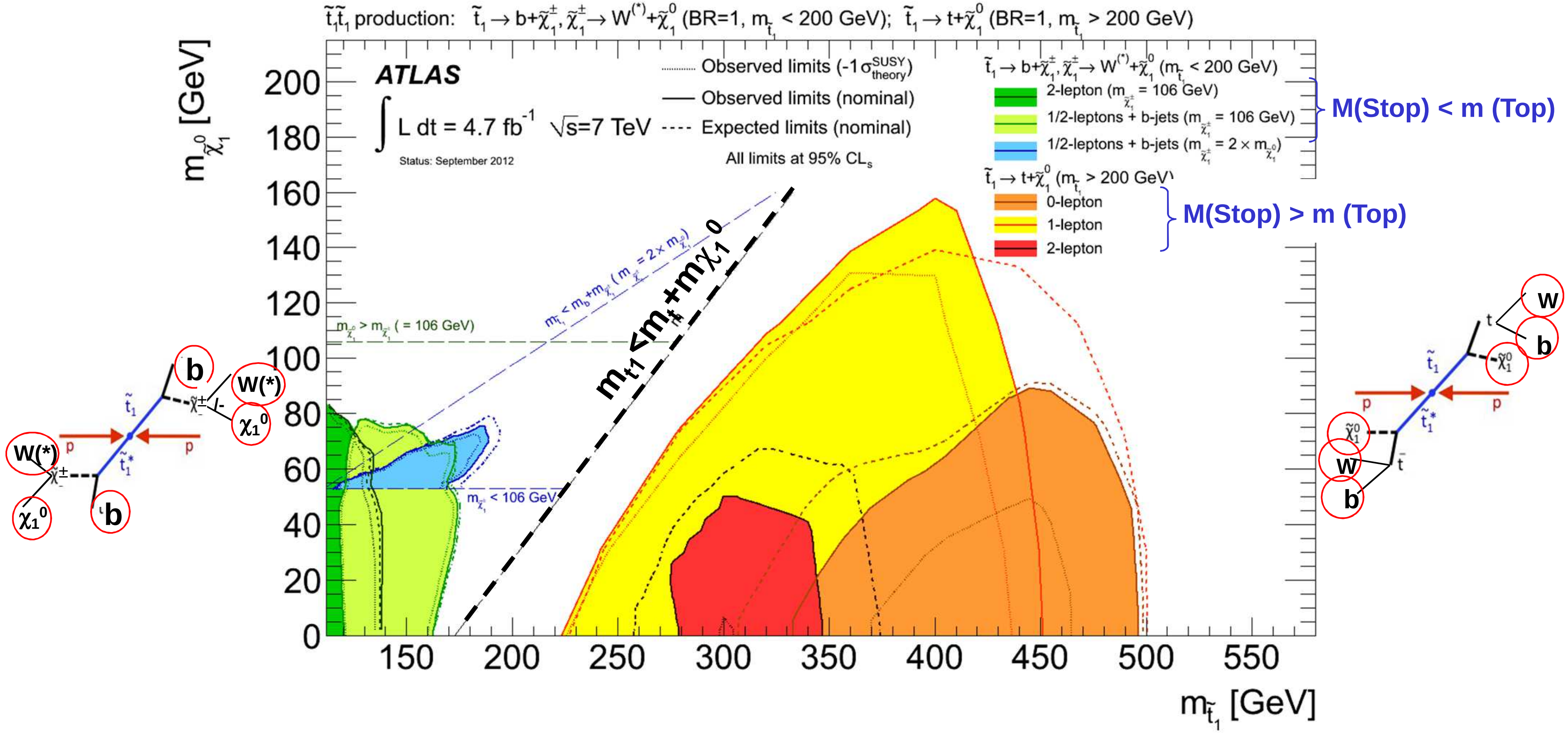
➔ Build few exclusive analyses to catch the beast !

# Natural SUSY searches (3)

arXiv:1208.1447, 1208.2590, 1208.4305, 1209.2102, 1209.4186

## ❑ Final results on direct stop at √s=7 TeV, 5 fb$^{-1}$

- Dedicated effort in large number of exclusive final states

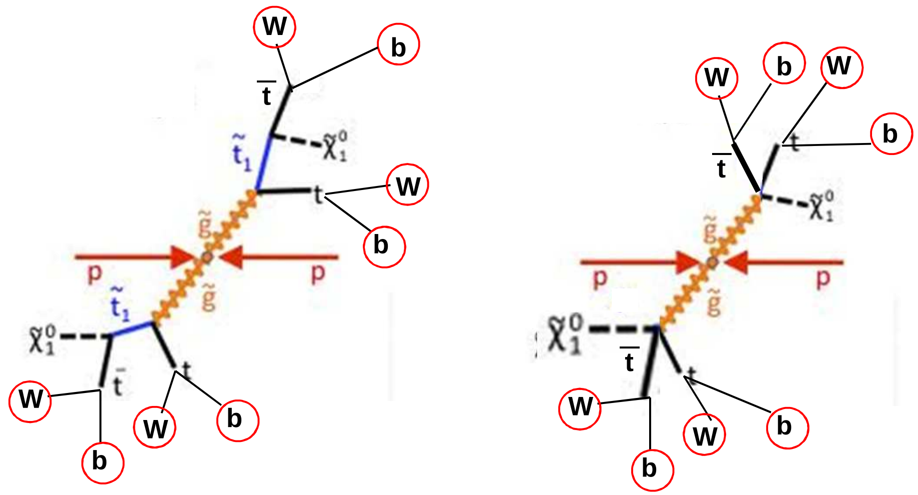



➔ "If you cover the white then Weak scale SUSY is probably dead" R. Barbieri (ICHEP2012)

# Natural SUSY searches (4)

- **Increase again complexity: $m_{\tilde{g}}$ ~ O (1 TeV)**
  - Stop in gluino cascade dominates
  - Stop on-shell (2 body) or off-shell (3 body decay)

| 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 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |




Final state (4 tops !!): =**4b, 4W + High MET**

➔ Need ttbar killers : 0l+≥3b-jets+MET, 0l+6-9 jets, Same Sign 2l+jets+MET, 3l+jets+MET

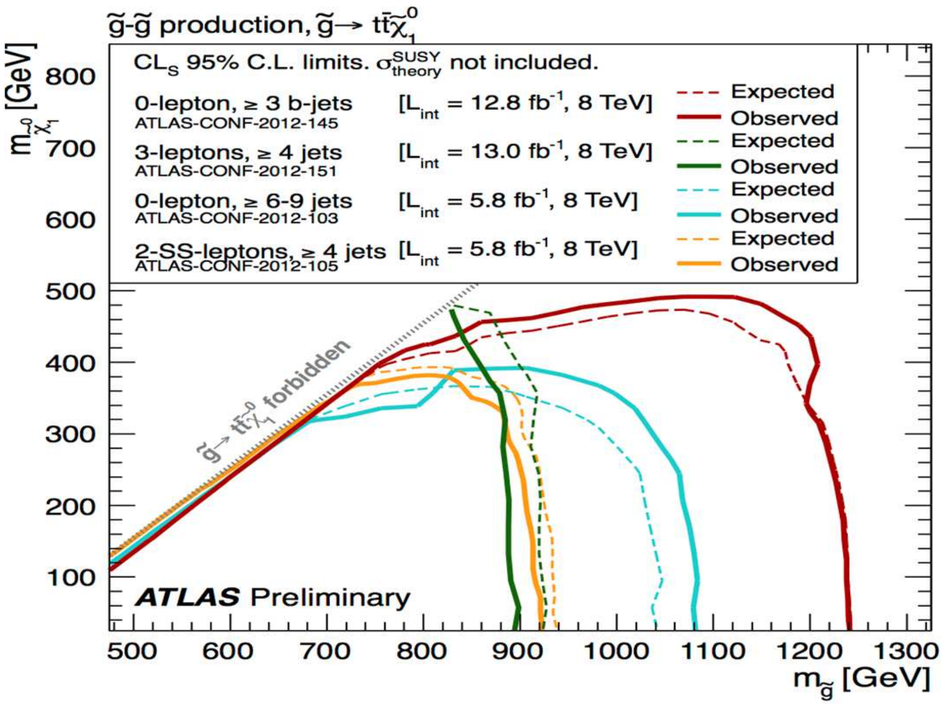
# Natural SUSY searches (5)

ATLAS-CONF-2012-103/105/145/151

## ❑ Current status at √s=8 TeV

8 TeV 8 TeV 8 TeV 8 TeV

- Complementarity between analyses exists
  - ✓ High Mass gluino (3b-jets, 0lepton+6-9jets) and compressed spectrum (2lepton Same Sign, 3leptons+jets)
- … and will be improved for final 8 TeV results




➔ Exclude $m_{\tilde{g}}$<1200 GeV for $m_{\tilde{\chi}_1^0}$<450 GeV

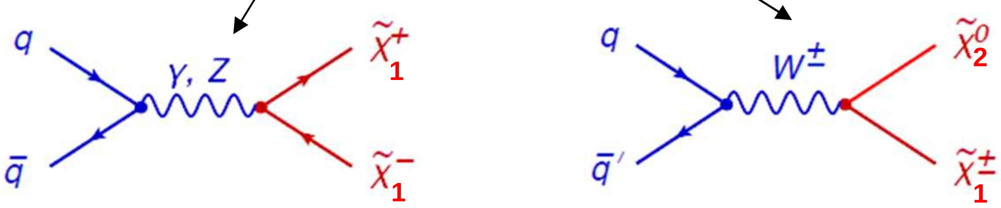
# Natural SUSY searches (6)

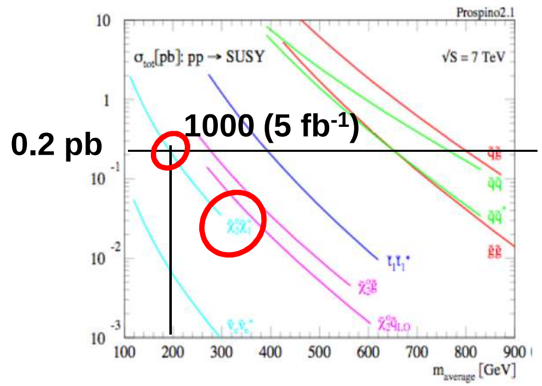
| Names | Spin | $P_R$ | Gauge Eigenstates | Mass Eigenstates |
|---|---|---|---|---|
| Higgs bosons | 0 | +1 | $H_u^0\ H_d^0\ H_u^+\ H_d^-$ | $h^0\ H^0\ A^0\ H^\pm$ |
| squarks | 0 | −1 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\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

## ❑ If $\tilde{q}$ / $\tilde{g}$ too heavy ➔ only EWK Production !

- Gauginos produced in s-channel mediated by $\gamma$, Z, W or $h^0/H^0/A^0$
- Accessible @ 5 fb$^{-1}$: $\chi_1^\pm\chi_2^0$ and $\chi_1^+\chi_1^-$

$\sigma_2 < \sigma_1$ $\sigma_1$




- Focus on gaugino leptonic decays to remove hadronic background
  - ✓ Via an intermediate lepton (BR=50%l, 50%ν)
  - ✓ Via an onshell/offshell W (BR~33%) or Z(BR~10%)
  - ➔ Jet veto to remove ttbar
- $\sigma$(WW→2l2ν)~50 pb and $\sigma$(WZ→3l1ν)~20 pb most dangerous backgrounds

➔ 2 or 3 leptons in final states and no jets

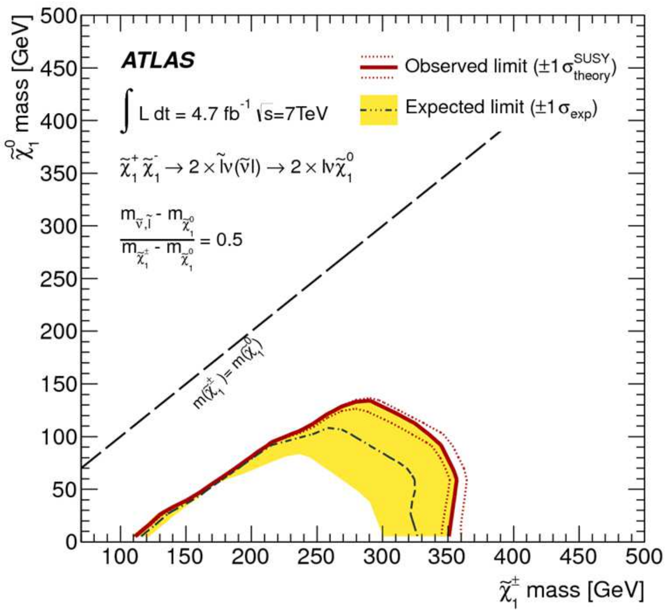
# Natural SUSY searches (7)

arXiv:1208.2884

❑ **Final results at $\sqrt{s}$=7 TeV, 5 fb$^{-1}$ for direct charginos production**

- Consider $\tilde{\chi}_1^+\tilde{\chi}_1^-$ in leptonic decays ➔ 2 leptons [e,μ] + MET + **jet veto**
- Exploit simple topology by cutting on $m_{T2}$ (~$m_{CT}$ for direct $\tilde{b}$). Helps to reduce WW background

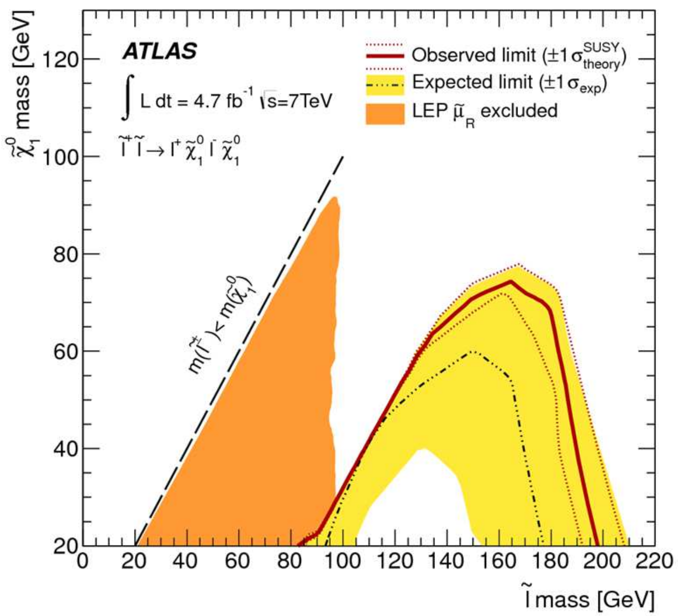
Interpret w intermediate slepton (50% $\tilde{l}$, 50% $\tilde{\nu}$)
$\tilde{\chi}_1^\pm$ / $\tilde{\chi}_2^0$ wino-like, $\tilde{\chi}_1^0$ bino-like




Nice

by-product !

Direct slepton production



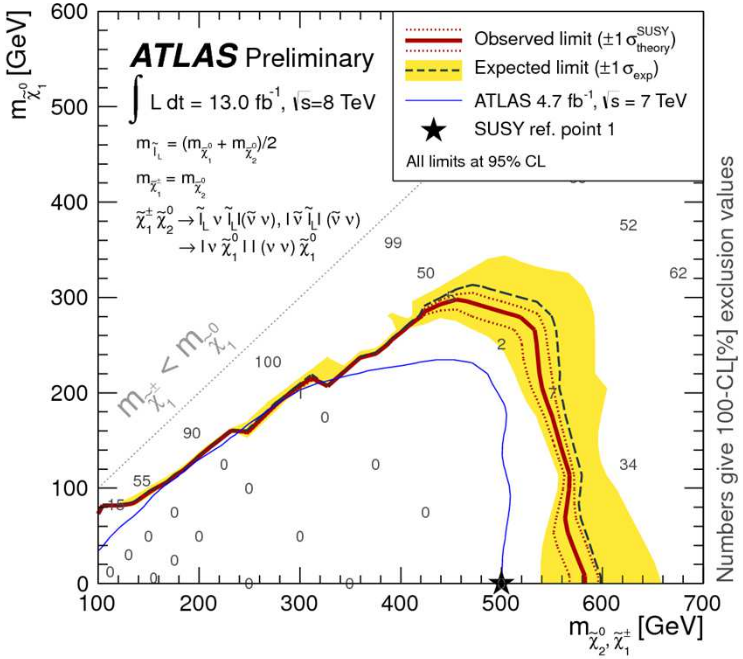

➔ Sensitive also to direct slepton production (beyond LEP!)

# Natural SUSY searches (8)

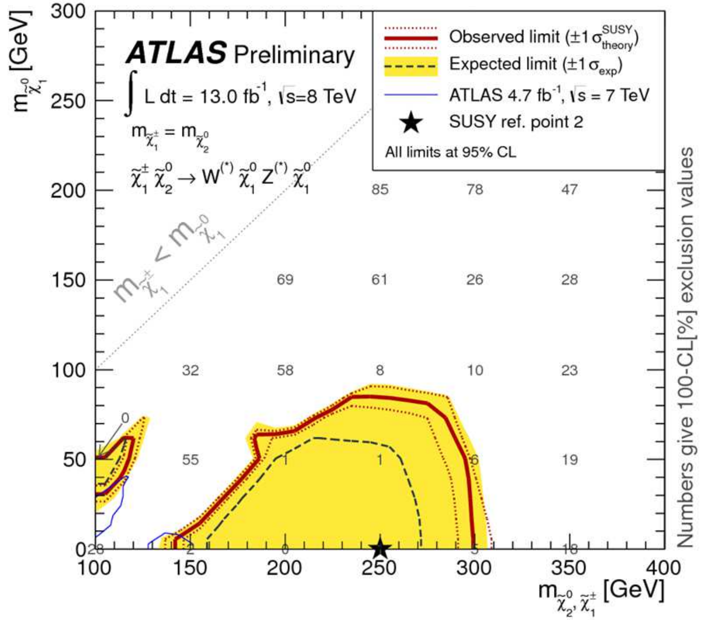
ATLAS-CONF-2012-154

- **First results at $\sqrt{s}$=8 TeV, 13 fb$^{-1}$ for associated production**
  - Consider $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ in leptonic decays ➔ 3 lept. [e,μ] + MET+ Z-veto/request and/or $m_T$(l,ν)>90 GeV
  - Gain by combining with 2leptons signal regions (one missing lepton)

Interpret w intermediate slepton (50% $\tilde{l}$, 50% $\tilde{\nu}$)
$\tilde{\chi}_1^{\pm}$ / $\tilde{\chi}_2^0$ wino-like, $\tilde{\chi}_1^0$ bino-like




Interpret w intermediate W / Z
$\tilde{\chi}_1^{\pm}$ / $\tilde{\chi}_2^0$ wino-like, $\tilde{\chi}_1^0$ bino-like



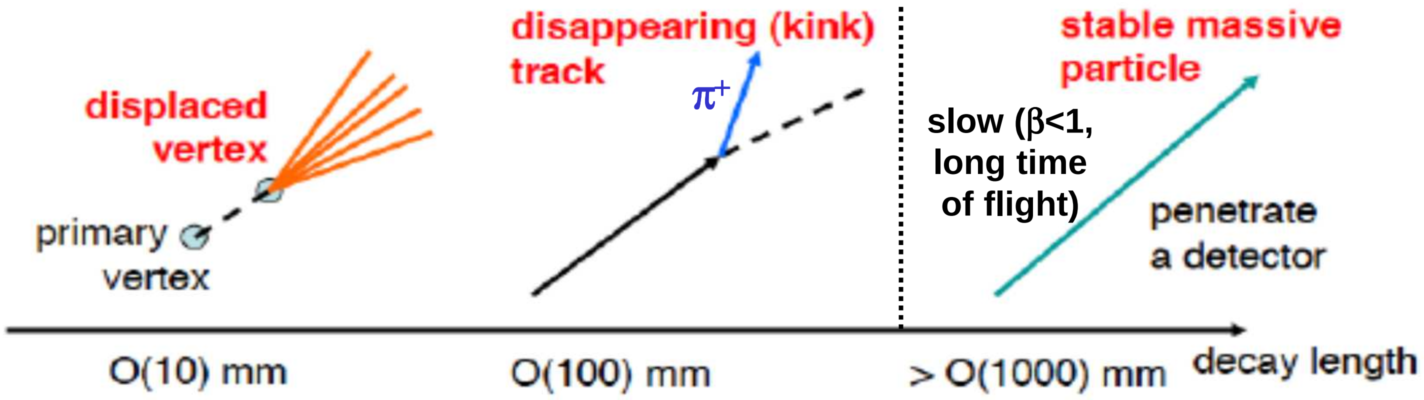

➔ See back up for more complex models (pMSSM)

# Long-Lived Particles

## ❑ Three main mechanisms

- R-Parity violation: Lifetime proportional to $\lambda^{-2}, \lambda'^{-2}, \lambda''^{-2}$ ➔ Displaced vertex if $\lambda$ or $\lambda'$ or $\lambda''$~O($10^{-5}$)
- Low $\Delta m(\tilde{\chi}_1^+ - \tilde{\chi}_1^0)$~100 MeV in AMSB ➔ Low $\pi$ emitted, kinked track
  Low $\Delta m(\tilde{g}/\tilde{q} - \tilde{\chi}_1^0)$ for coloured particles ➔ R-hadron ($\tilde{g}$ or $\tilde{q}$)
- Weak coupling to $\tilde{G}$ ($C_{grav}$>>1) in GMSB ➔ Stable sleptons

**MetaStable** **Stable**



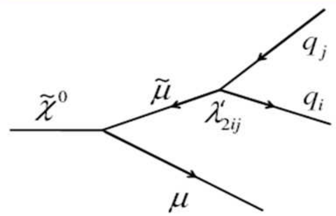

➔ A bunch of striking signatures, not present in the standard Model !!

# Long-Lived Particles (1)

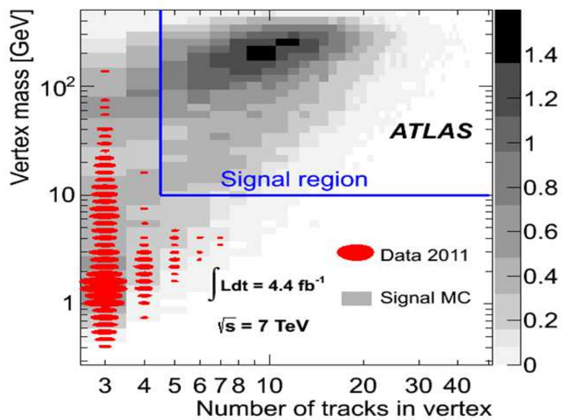
arXiv:1210.7451

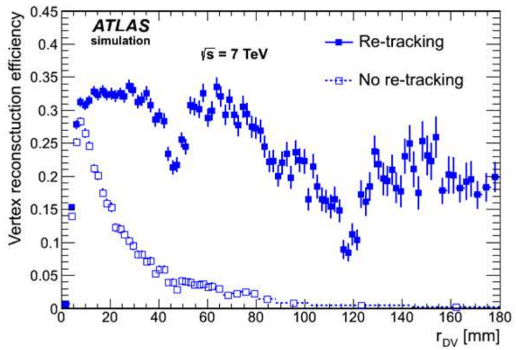
## ❑ High mass displaced vertex with 4 tracks and a muon

- Assume RPV with $\lambda'_{2ij} \neq 0$: $\chi_1^0$ decay ! ⟶

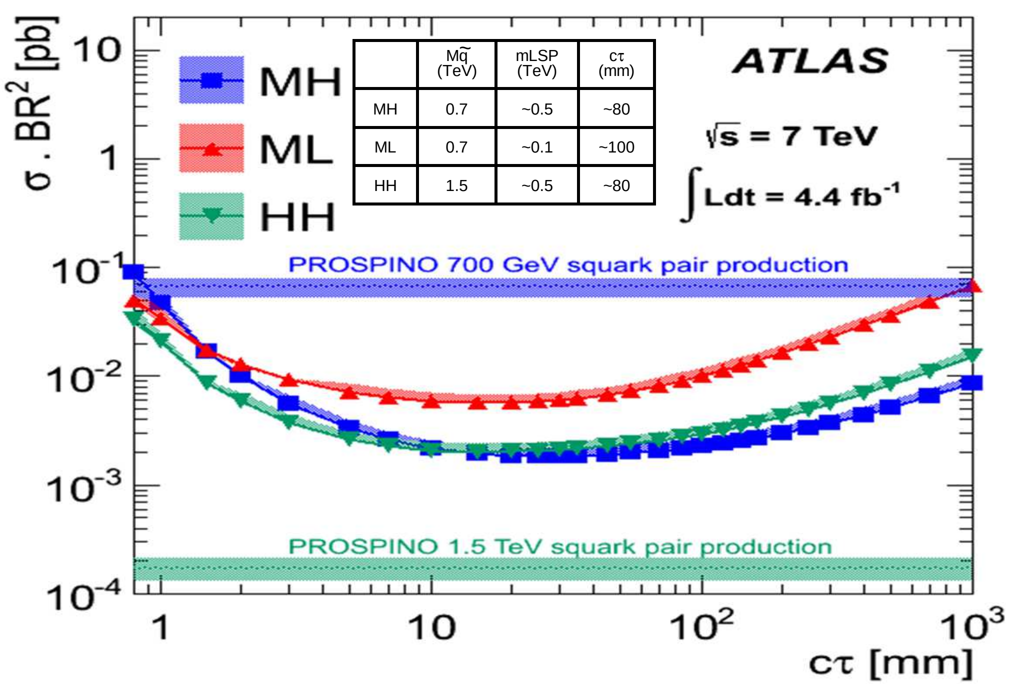



- Design a background-free analysis in $M_{vertex} - N_{track}$ plane
- Build up a dedicated tracking to increase signal efficiency




$\tilde{q}\tilde{q} \rightarrow qq\ \tilde{\chi}_1^0 \tilde{\chi}_1^0$

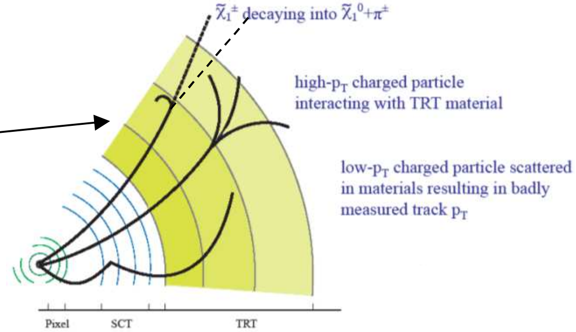


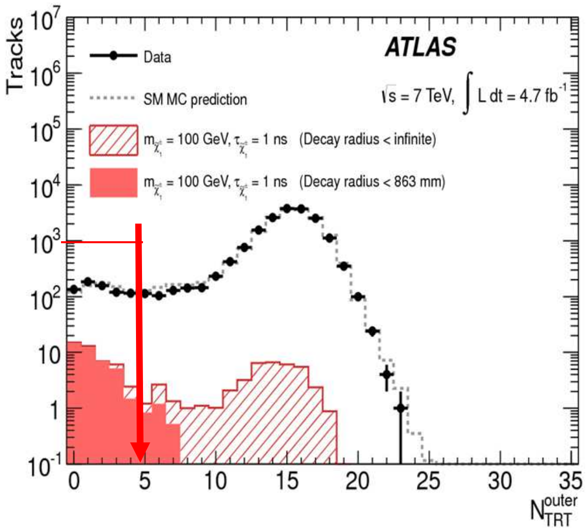
# Long-Lived Particles (2)

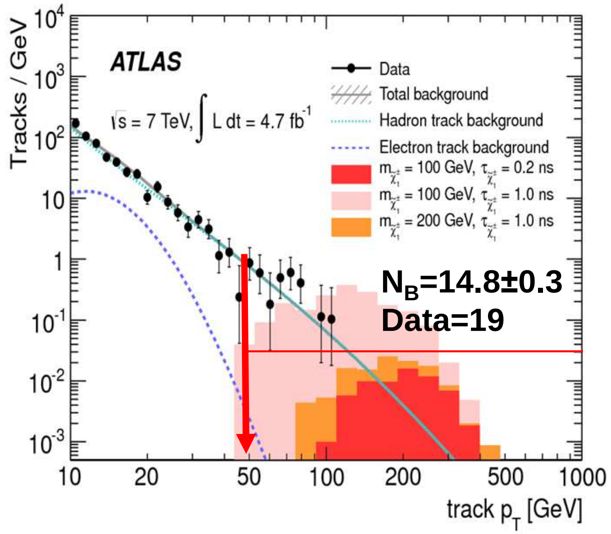
arXiv:1210.2852

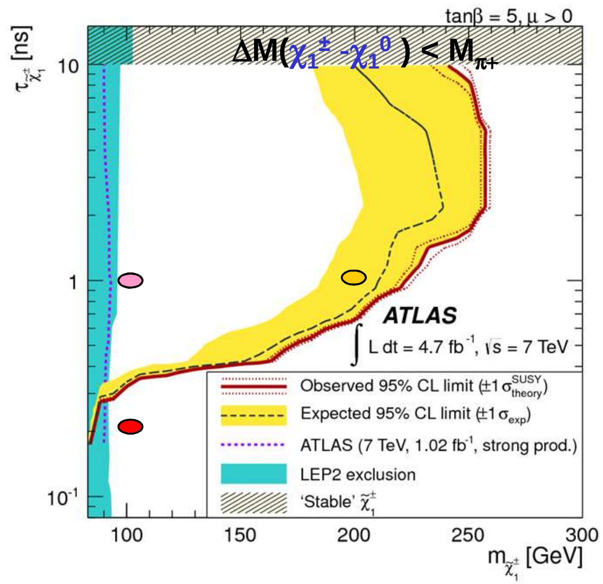
## ❑ Direct production of metastable $\chi_1^{\pm}$ *

- Motivated by AMSB, but model independent results
  - ✓ $\chi_1^{\pm} \rightarrow$ soft $\pi^{+}$ + $\chi_1^{0}$ : Kinked track in the TRT
- Remove background : $N_{TRT}^{Outer}$ + highest $p_T$ isolated track




➔ For 0.1<cτ<3 m exceed previous LEP2 limit !

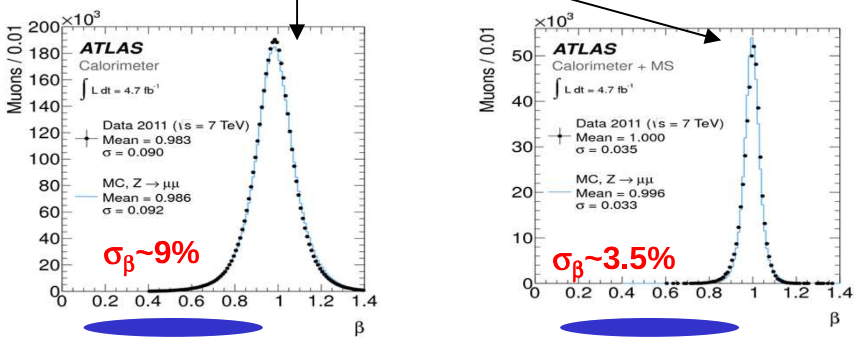
* σ~10/1pb for m=100/200 GeV

# Long-Lived Particles (3)

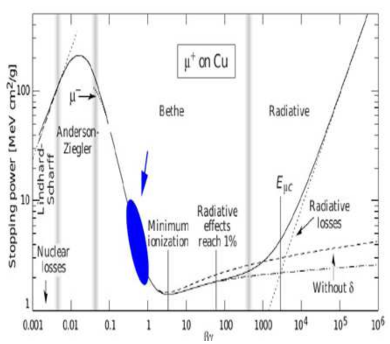
arXiv:1211.1597

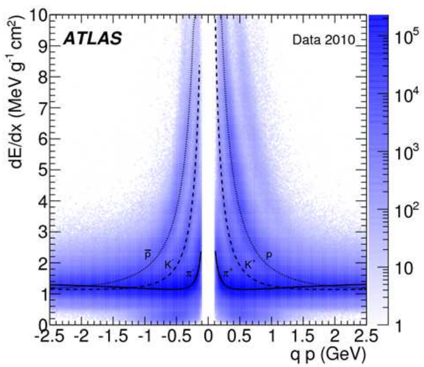
## ❑ Mass reconstruction of pair produced stable particles

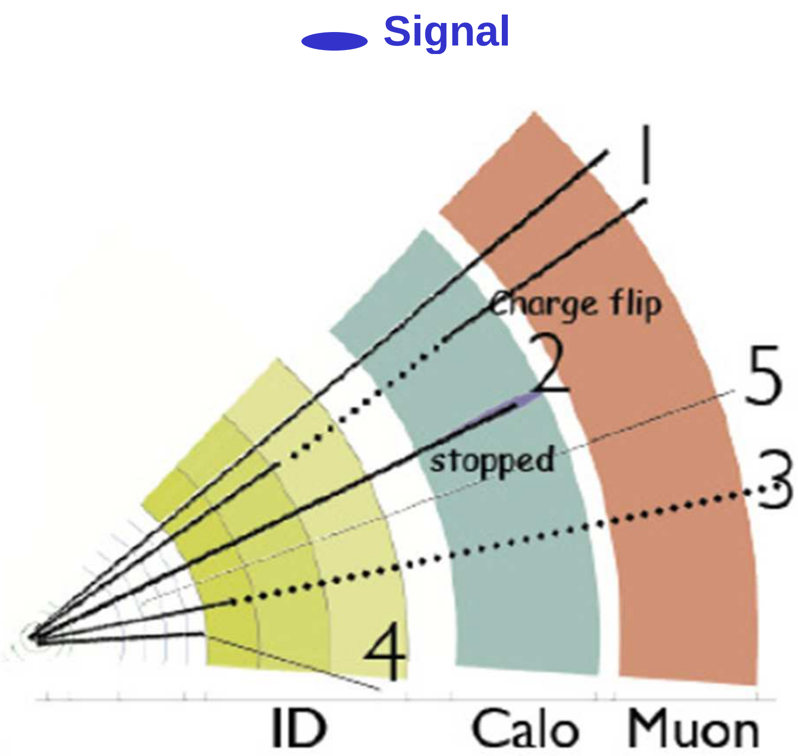
1. Start from one (or two) high pT isolated track → p
2. Measure β (calo or calo+Muon Spectrometer)




3. Measure βγ (invert Bethe-Bloch) from track clusters




➔ Add the 2 or 3 information together and compute $M = p/\beta\gamma$

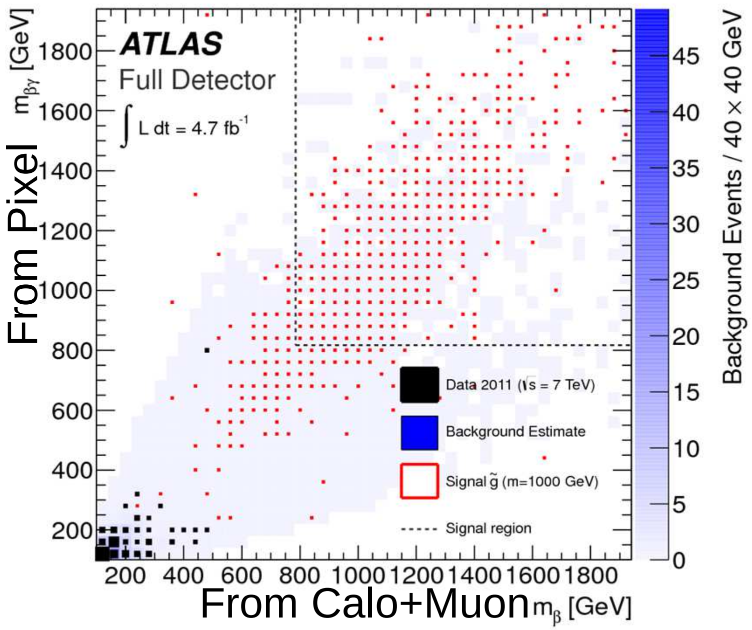
# Long-Lived Particles (4)

arXiv:1211.1597

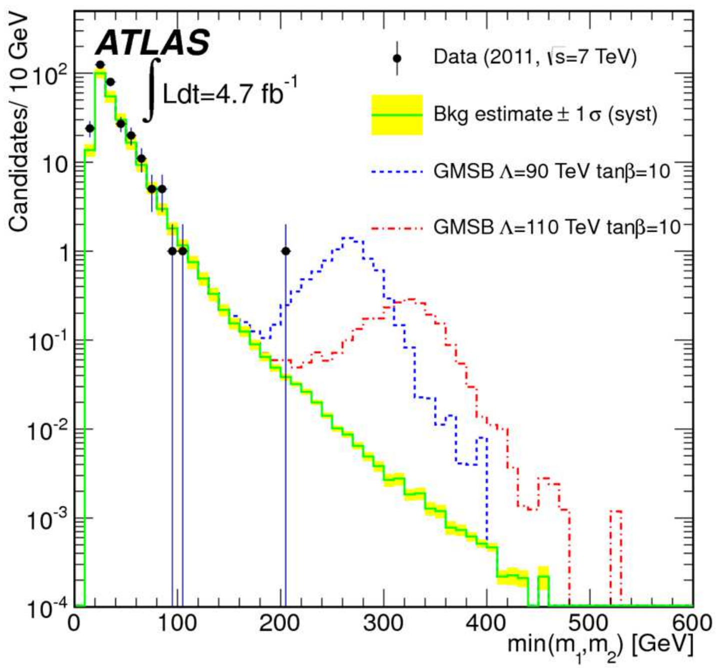
## ❑ Mass distributions

- Cut and count in mass ranges. Very low level of background

R-hadrons: Full detector




Slepton searches (2 candidates)




**Exclude 1 TeV R-hadron ($\tilde{g}$) and ~600-700 GeV R-hadron ($\tilde{t}$, $\tilde{b}$)**

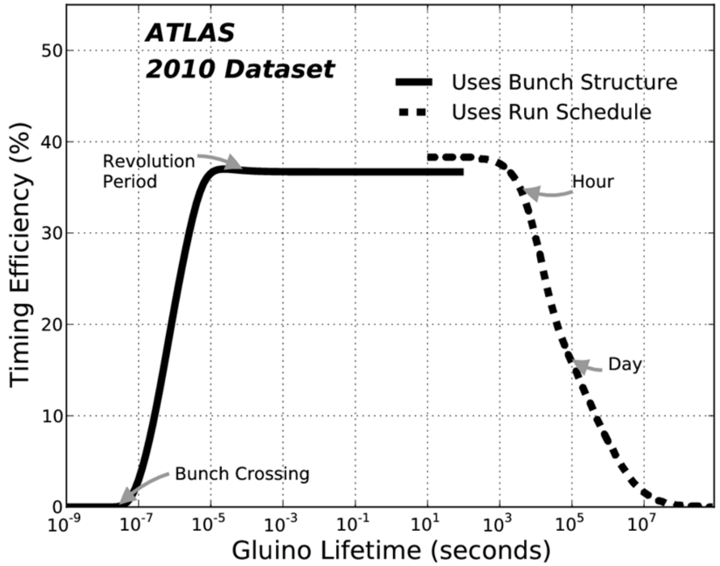
**Exclude ~300 GeV sleptons (assuming direct production)**

# Long-Lived Particles (5)

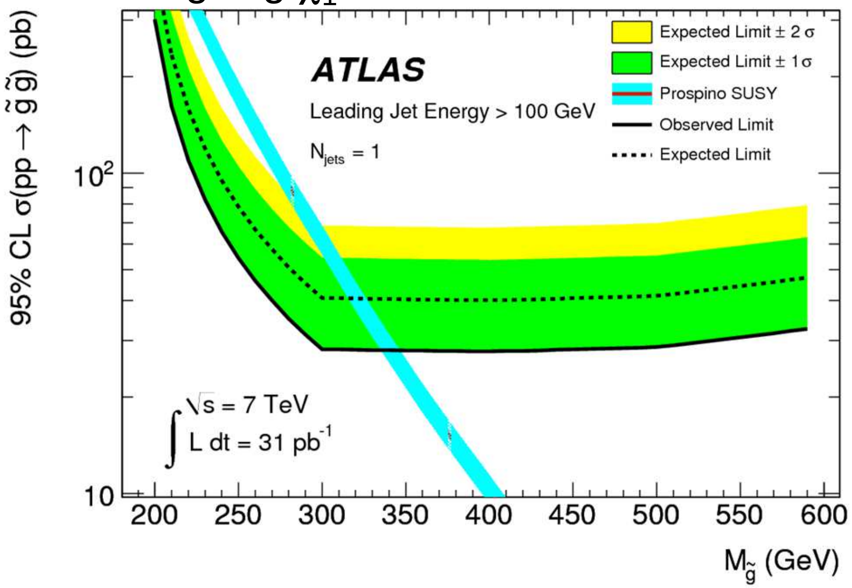
arXiv:1201.5595

## ❑ R-hadrons can also stop and decay later

- Very well motivated (Split SUSY) : stopped gluino only particle reachable at LHC !
- High pT jets in absence of collisions (gaps of LHC beam structure)
- Background = calorimeter noise, cosmics and beam halo not SM !
  - ➔ Control samples: 2010 low lumi run, cosmic runs, beam halo tag&probe in opposite endcaps




$\tilde{g} \rightarrow g\, \tilde{\chi}_1^0$




➔ $M_{\tilde{g}} < 340$ GeV for $M\chi=100$ GeV excluded for 10 $\mu$s $< \tau <$ 15 min

# RPV

## ❑ R-parity violating search at LHC

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

- Proton decays only forbids simultaneous violation of lepton and baryon number

From H. Dreiner

Multilepton production (including taus)

Resonances (2jets, 2x2 jets, 2x3 jets, eμ, eτ, mτ)

Note: Absence of Z and Importance of taus

| | Signature | Model |
|---|---|---|
| 1) | 4 charged leptons: $e^+e^+\mu^-\mu^-$ | $\chi_1^0$–LSP, $LL\bar{E}$, $\tilde{\tau}$–LSP, $LL\bar{E}$ |
| 2) | 2 leptons, 2 taus: $e^+e^+\tau^-\tau^-$ | $\chi_1^0$–LSP, $LL\bar{E}$, $\tilde{\tau}$–LSP, $LQ\bar{D}$ |
| 3) | 6 jets or 2 w/ substructure | $\chi_1^0$–LSP, $\bar{U}\bar{D}\bar{D}$ |
| 4) | like-sign dileptons + jets | $\chi_1^0$–LSP, $LQ\bar{D}$ |
| 5) | dilepton resonance | $LL\bar{E} \otimes LQ\bar{D}$ |
| 6) | mono lepton | $LL\bar{E} \otimes LQ\bar{D}$ |
| 7) | dijet resonance | pure $LQ\bar{D}$ |
| 8) | like sign ditau's $\tau^-\tau^-$ + 6jets | $\tilde{\tau}$–LSP, $LQ\bar{D}$ |

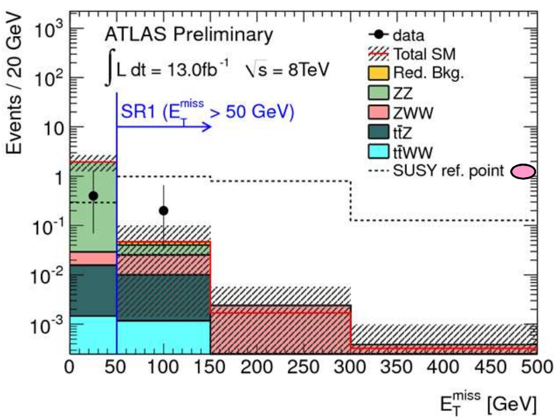
➔ Generally: lower background (no LFV nor BNV in SM) and MET than RPC

# RPV (1)

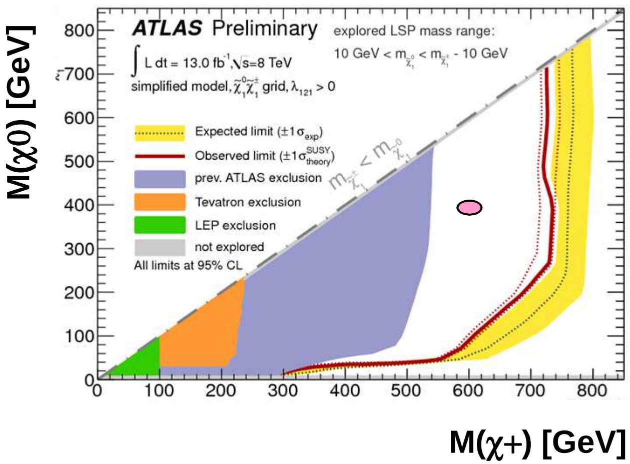
ATLAS-CONF-2012-153

## ❑ Multilepton (≥4 isolated e, μ) search

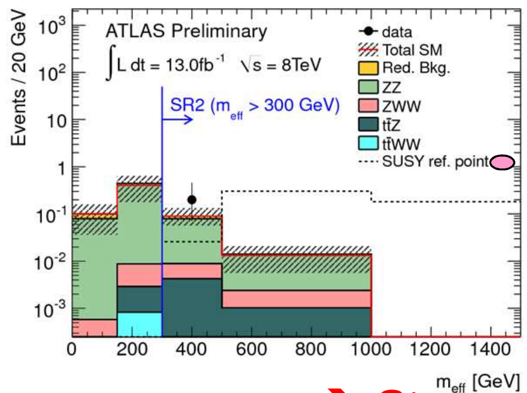
- 2 signal regions: Z-veto + cuts on MET or Meff
- Background dominated by ZZ



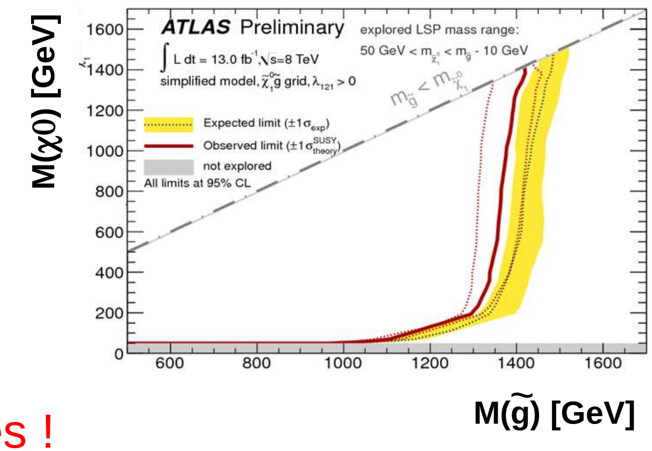

**Simplified Models with $\lambda_{121}, \lambda_{122} \neq 0$ and $\chi_1^0 \rightarrow lll'$**




$pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow W\tilde{\chi}_1^0\, W\tilde{\chi}_1^0$




$pp \rightarrow \tilde{g}\tilde{g} \rightarrow qq'\tilde{\chi}_1^0 qq'\tilde{\chi}_1^0$



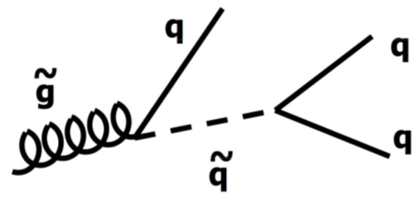

➔ Stronger limit than RPC analyses !

# RPV (2)

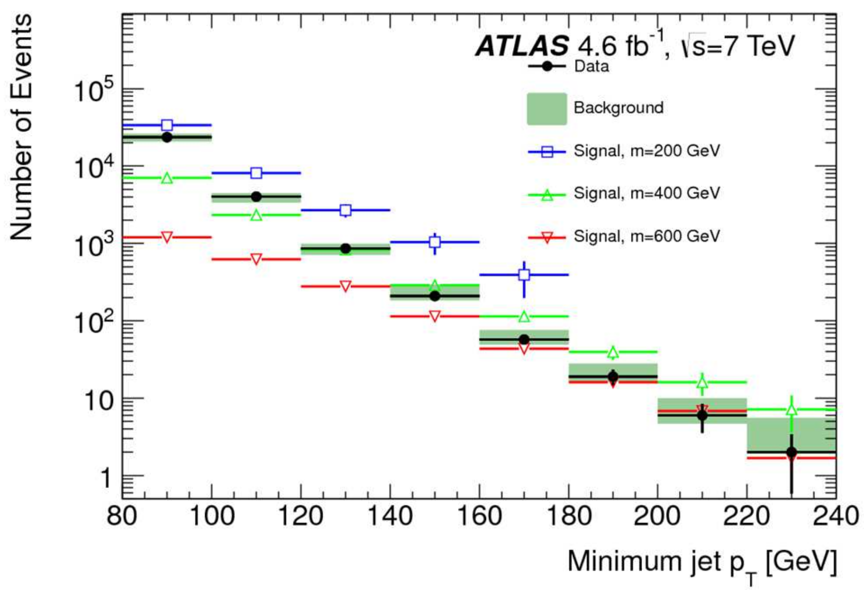
arXiv:1210.4813

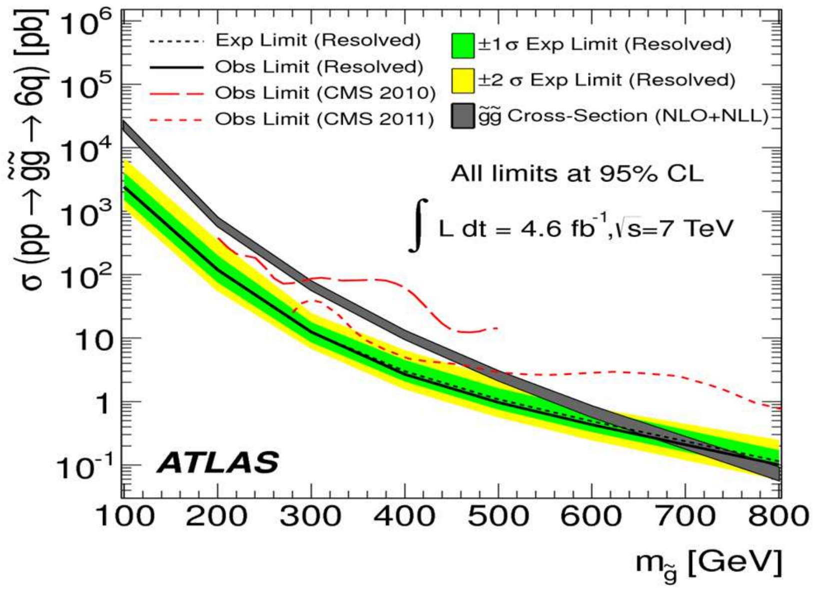
## ❑ 2x3 jets resonance

- Motivated by RPV models with gluino →jjj
- Resolve all 6-jets (high mass) or exploit jet collimation (low mass)
- Multi-jets background data driven
- Note: ISR systematics not taken into account for signal




$m(\tilde{q}) >> m(\tilde{g})$



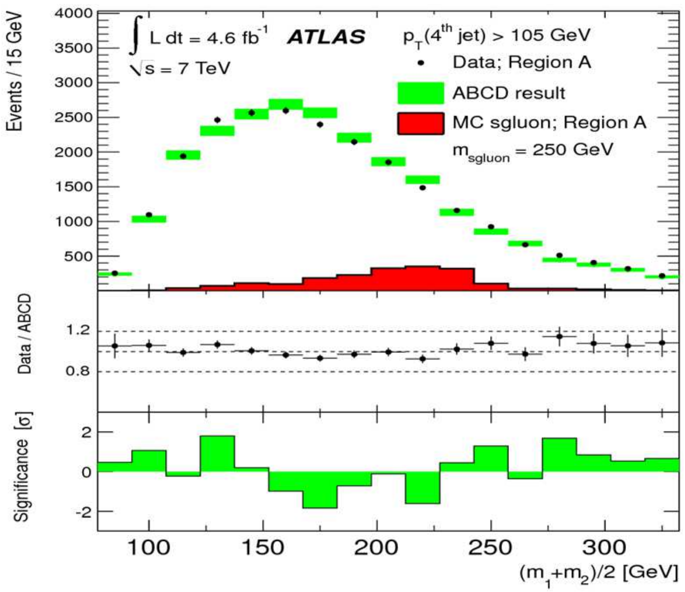

➔ Exclude Gluino masses < 670 GeV. Huge improvement over CMS

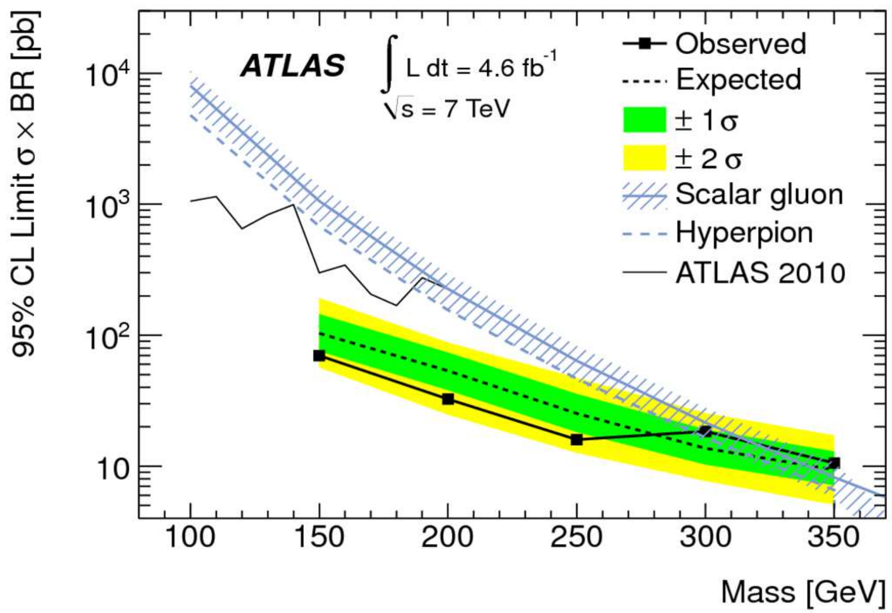
# Beyond MSSM

arXiv:1210.4826

## ❑ Massive color scalars : 2x2 jets final state

- R-parity=1 particles predicted beyond MSSM, in compositeness models
- sgluon (→ gg) pair produced: 2 resonances $M_1$, $M_2$ reconstructed with ≥4 jets pT>80 GeV
- Reduce combinatorics by minimizing $|\Delta R_1 - 1| + |\Delta R_2 - 1|$



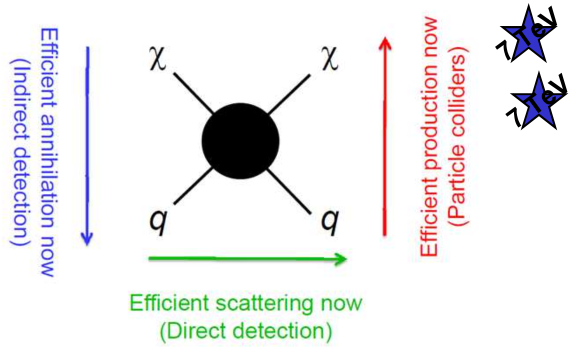

➔ Exclude scalar gluons for masses below 300 GeV

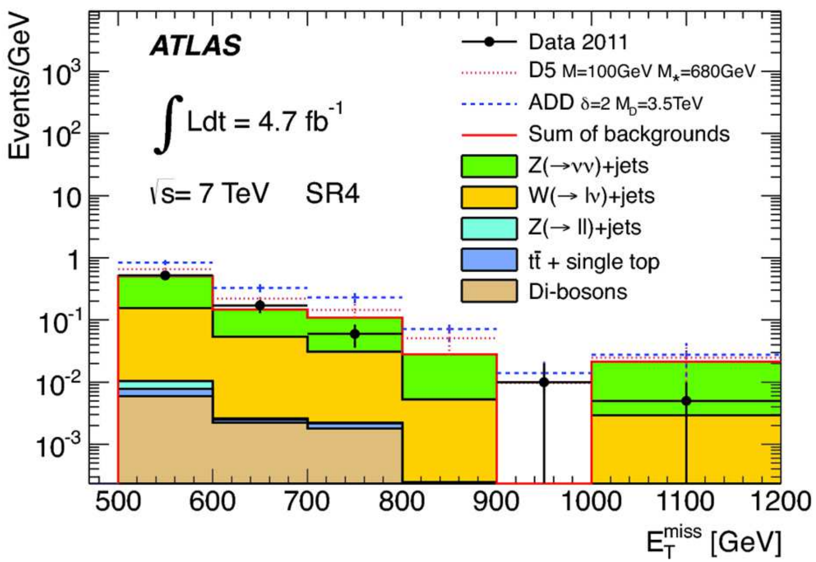
# Dark Matter

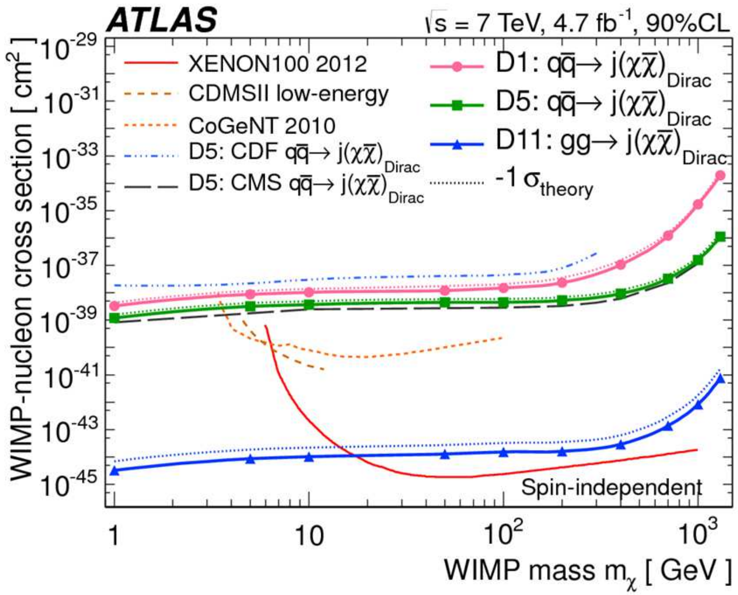
arXiv:1209.4625, 1210.4491

## ❑ Monojet (MonoPhoton) signatures

- Dark Matter ($\chi$) may be produced at LHC
  ➔ detectable only if initial state radiation(s)
- Enhancement in high MET,pT(jet1)>550 GeV Signal Region (SR4)
- Converted in $\sigma$(WIMP-nucleon) assuming effective operators




➔ Competitive with dedicated Dark Matter experiments

# Conclusions

- ❑ **ATLAS seriously bites in Weak scale SUSY between 100 GeV and 1 TeV**

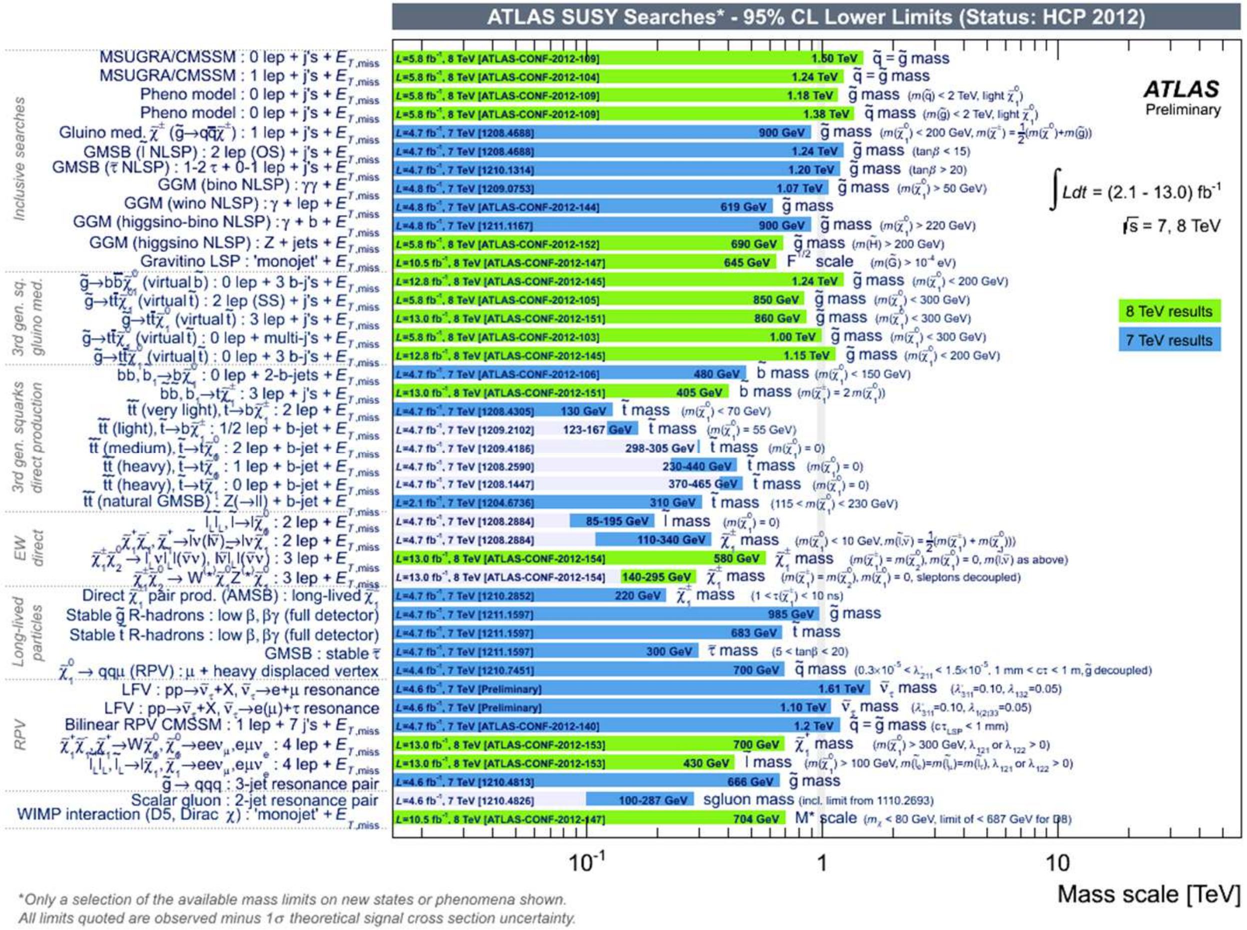
1.Inclusive searches

2.Natural SUSY

3.Long-Lived Particles

4.RPV

5. Beyond MSSM, DM



# Some usefull links

- **Bibliography** http://pralavop.web.cern.ch/pralavop/phd.html
- **ATLAS public results** https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- **Questions** pralavor@cppm.in2p3.fr

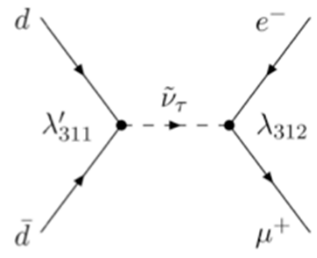
# SPARES

# RPV (2)

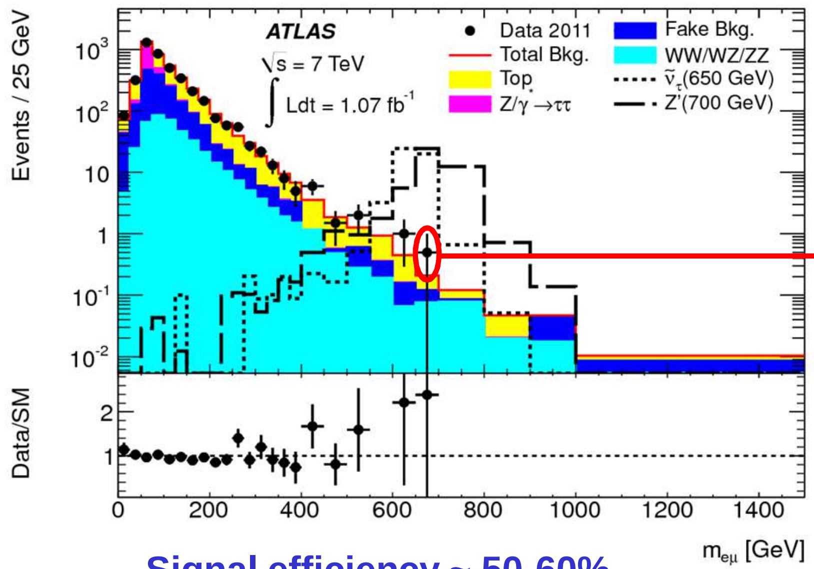
arXiv:1205.0725

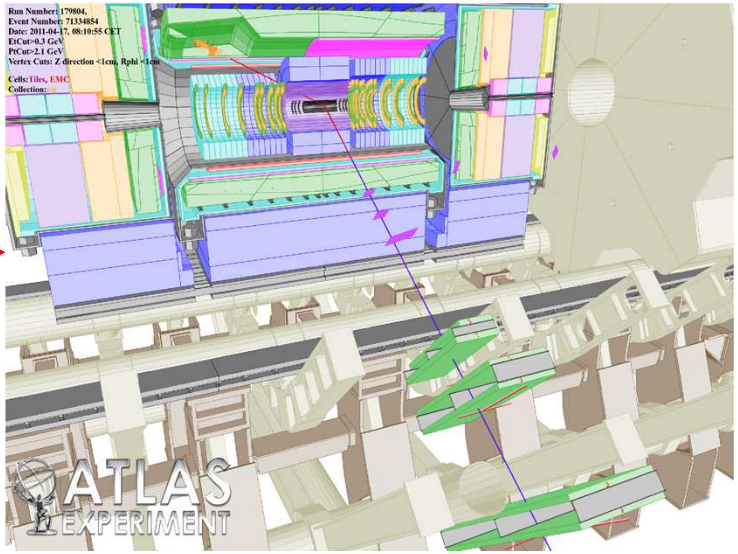
## ❑ Lepton flavor violation resonance

- Lepton flavor violation brought by sneutrinos decay (s-channel)
- Look in eμ spectrum inside +/-3 σ




$\Delta\phi$ (e, μ)~π , MET=132 GeV, no Jet !




**Signal efficiency ~ 50-60%**

# SUSY particle decay

- **Once mass spectrum known, theoretically computable decay rate**
  - Mix of on-shell (2 body decay) and off-shell (3-body decay)

**MSSM: 29 sparticles + 5 Higgs undiscovered**

| 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 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0$ (Bino) $\tilde{W}^0$ (Wino) $\tilde{H}_u^0\ \tilde{H}_d^0$ (Higgsino) | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm$ (Wino) $\tilde{H}_u^+\ \tilde{H}_d^-$ (Higgsino) | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |

**Main decay channels in MSSM**

$h \to bb, WW, \tau\tau$; $H^0 \to hh, WW, tt, bb$; $A^0 \to tt, bb$; $H^{+/-} \to \tau\nu, tb$

$\tilde{q} \to q\tilde{g}, q\tilde{\chi}_1^0, q'\tilde{\chi}_1^{+/-}, q'W^{(*)}\tilde{\chi}_1^0$ { $\tilde{q}_L \to q\tilde{\chi}_{1(2)}^0, q'\tilde{\chi}_1^{+/-}$ ($\tilde{\chi}_2^0$ wino) ; $\tilde{q}_R \to q\tilde{\chi}_1^0$ ($\tilde{\chi}_1^0$ bino) }

$\tilde{g} \to q\tilde{q}, q\tilde{q}\tilde{\chi}_1^0, q\tilde{q}'\tilde{\chi}_1^{+/-}$

**STRONG**

$\tilde{l} \to l\tilde{\chi}_{1(2)}^0, \nu\tilde{\chi}_1^{+/-}$ → $\tilde{l}_L \to l\tilde{\chi}_{1(2)}^0, \nu_l\tilde{\chi}_1^{+/-}$ ($\tilde{\chi}_2^0$ wino)

$\tilde{\nu} \to \nu\tilde{\chi}_{1(2)}^0, l\tilde{\chi}_1^{+/-}$ → $\tilde{l}_R \to l\tilde{\chi}_1^0$ ($\tilde{\chi}_1^0$ bino)

$\tilde{\chi}_2^0 \to W^{(*)}\tilde{\chi}_1^{+/-}, Z^{(*)}\tilde{\chi}_1^0, \tilde{l}l, \tilde{\nu}\nu, \tilde{q}q$

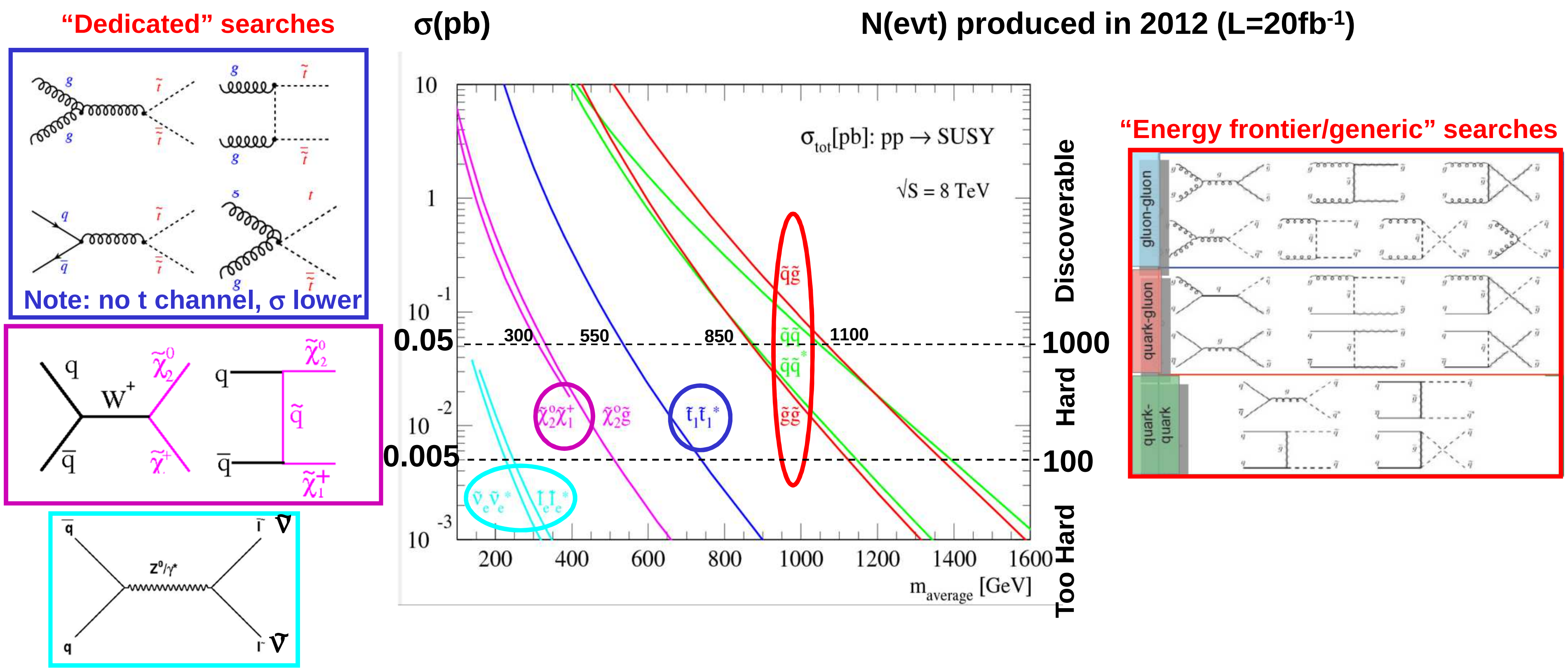
$\tilde{\chi}_{1(2)}^{+/-} \to W^{(*)}\tilde{\chi}_1^0, Z^{(*)}\tilde{\chi}_1^{+/-}, l\tilde{\nu}, \nu\tilde{l}; qq'$

**Electro-Weak**

➔ Predictable but huge combinatorics: (Possible decays) x (mass spectrum) !

# SUSY production at LHC (8 TeV)

❑ **R-Parity conserved ➔ sparticles are paired produced at LHC**




Spin structure of SUSY spectrum (lots of scalars) : lower σ than other BSM models

➔ Searching for SUSY often means building dedicated/refined analyses

# SUSY Framework

## ❑ General (weak-scale) SUSY features

- **105** model parameters in the **MSSM**
- Not swamped by SUSY particle: SUSY is **broken**, but how ? (several models xxSB)
- R-parity ($P_R$ or $R_P$)= -1 SUSY, +1 SM

**MSSM: 29 sparticles + 5 Higgs undiscovered**

| 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 | $\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ | (same) |
| | | | $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ | (same) |
| | | | $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$ | $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$ |
| sleptons | 0 | −1 | $\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ | (same) |
| | | | $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ | (same) |
| | | | $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$ | $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$ |
| neutralinos | 1/2 | −1 | $\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$ (Bino) (Wino) (Higgsino) | $\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$ |
| charginos | 1/2 | −1 | $\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$ (Wino) (Higgsino) | $\tilde{C}_1^\pm\ \tilde{C}_2^\pm$ |
| gluino | 1/2 | −1 | $\tilde{g}$ | (same) |
| goldstino (gravitino) | 1/2 (3/2) | −1 | $\tilde{G}$ | (same) |

**Some key parameters of MSSM**

- $\mu$ = SUSY version of the SM Higgs mass
- **tanβ** = Ratio of vacuum expectation values of $H_u/H_d$
- $\mathbf{m_h}$ = Mass of $h^0$ — $m_h^2 \leq M_Z^2 + \Delta m_{rad}^2 (A_t, \tan\beta, \mu, m_{\tilde{t}_{1,2}}, m_t, v^{**})$
- $\mathbf{m_A}$ = Mass of $A^0$ — Minimisation if MSSM Higgs potential (tree level) $\frac{1}{2}M_Z^2 = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2$
- $\mathbf{m_{H^+}}$ = Mass of $H^{+/-}$
- $\mathbf{m_{H_u}^2, m_{H_d}^2}$ from SUSY breaking
- $\mathbf{M_Q^2}$= Squark 3x3 mass term
- $\mathbf{M_L^2}$= Slepton 3x3 mass term

(the three above) **$=m_0^2$** at GUT scale*

- $\mathbf{M_1}$= Bino mass term
- $\mathbf{M_2}$= Wino mass term
- $\mathbf{M_3}$= gluino mass term

(the three above) **$= m_{1/2}$** at GUT scale*

- $\mathbf{A_{u,d,e}}$~Yukawa-like 3x3 matrix **$=A_o$** at GUT scale*

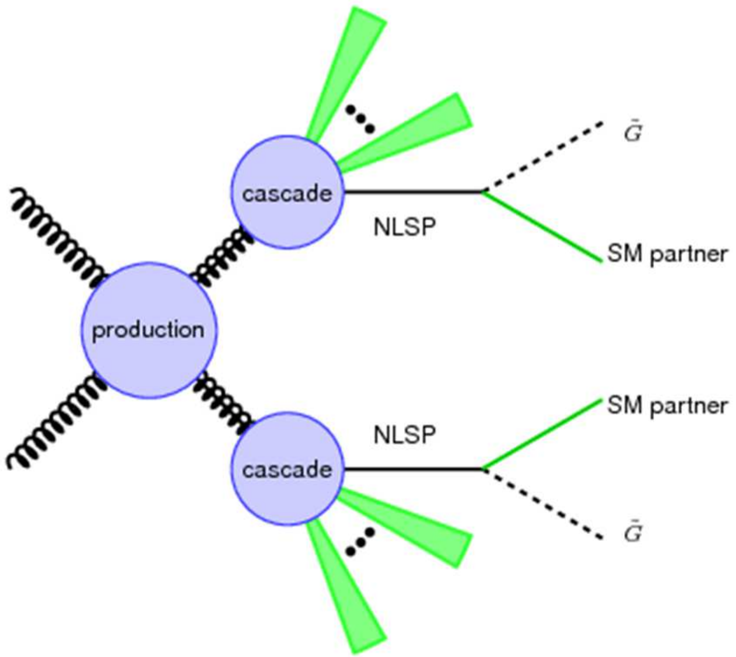
➔ A new world to explore (if it exists). Will take decades !

* In Planck scale-mediated SUSY breaking models like mSUGRA, ** $v=\sqrt{(v_u^2+v_d^2)}$

# GMSB Motived searches

## ❑ Motivation for multi-leptonic / photonic signatures

- Can not compete with inclusive 0lepton, 1lepton channels because of branching ratios
- GMSB: LSP is the gravitino and NLSP determines the event final states




JHEP 02 (2012) 115

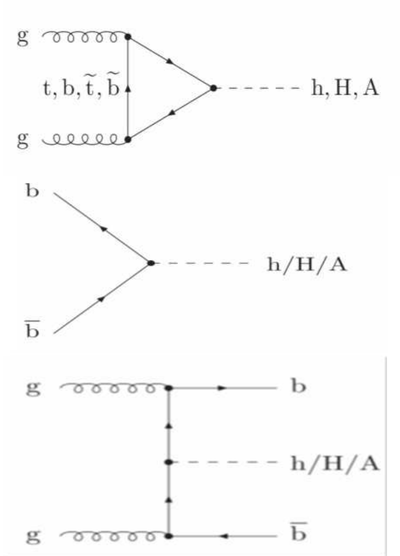
| NLSP type | Relevant final states (+MET) |
|---|---|
| bino | $\gamma\gamma$, $\gamma$+jets |
| wino | $\gamma\ell$, $\gamma\gamma$, $\gamma$+jets, $\ell$+jets, jets |
| $Z$-rich higgsino | $Z(\ell^+\ell^-)$+jets, $Z(\ell^+\ell^-)Z(\ell'^+\ell'^-)$, SS dileptons, jets |
| $h$-rich higgsino | $b$-jets, SS dileptons, jets |
| chargino | SS dileptons, OS dileptons, $\ell$+jets, jets |
| slepton | multileptons, SS dileptons, OS dileptons, $\ell$+jets, jets |
| squark/gluino | jets |
| stop | SS dileptons, OS dileptons, $b$-jets, $\ell$+jets, $\ell + b$-jets, $t\bar{t}$, jets |
| sbottom | $b$-jets, jets |

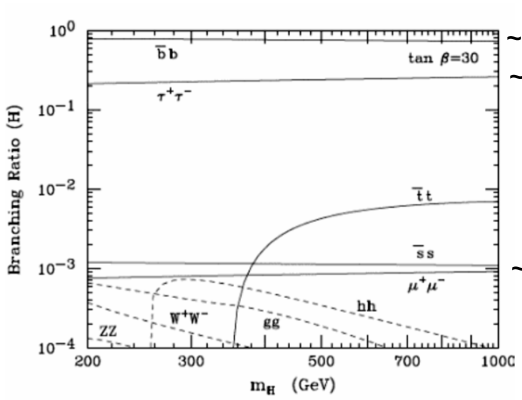
➔ Can seriously enhanced Z+jets+MET, τ+X+jets+MET, OS ll+jets+MET, γ+X+MET

➔ Note: inclusive 0lepton, 1lepton and SS dileptons also very strong

# MSSM Higgses (1)

❑ **Neutral Higgses : ϕ=A/H/h → ττ, μμ, (bb)**



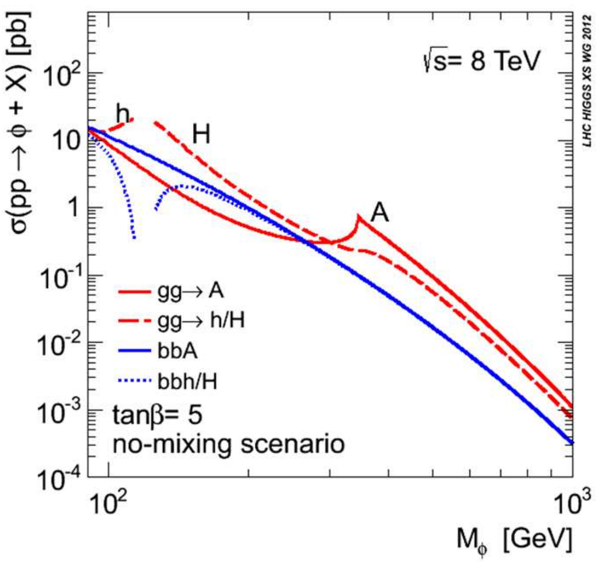



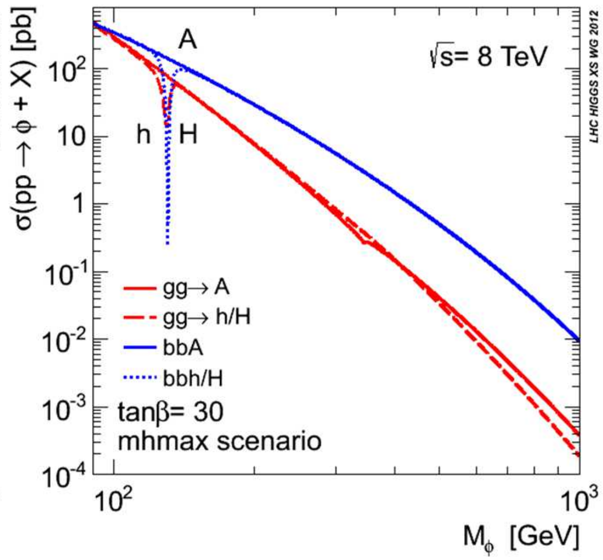

~90%

~10%

~0.04%

In SM at 7 TeV: σxBR(pp→H[125]+X) ~ 20 pb




✓No (or very weak) couplings of A/H to bosons

✓Two selections: b-tagged and b vetoes.

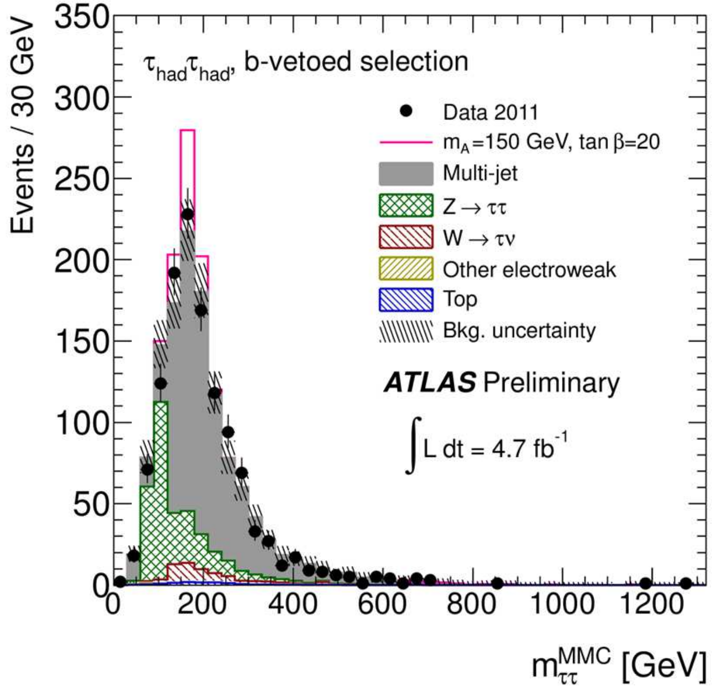
✓B-jet requirement dominates at high tan β

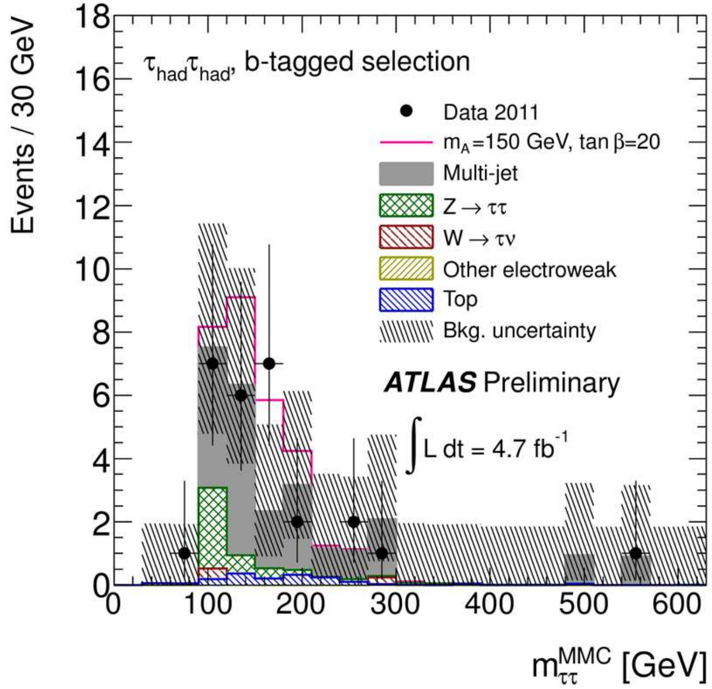
# MSSM Higgses (2)

ATLAS-CONF-2012-094

## ❑ Neutral Higgses : $\phi$=A/H/h → $\tau_{had}\tau_{had}$ (42%), $\tau_{had}\tau_{lep}$ (46%), $\tau_e\tau_\mu$ (6%)

- Main background : Z→$\tau\tau$ and Multijets
- 2 types of Signal Regions for the 2 production modes : b-vetoed or b-tagged
- Invariant $\tau\tau$ mass : visible energy or Missing Mass Calculator (MMC)



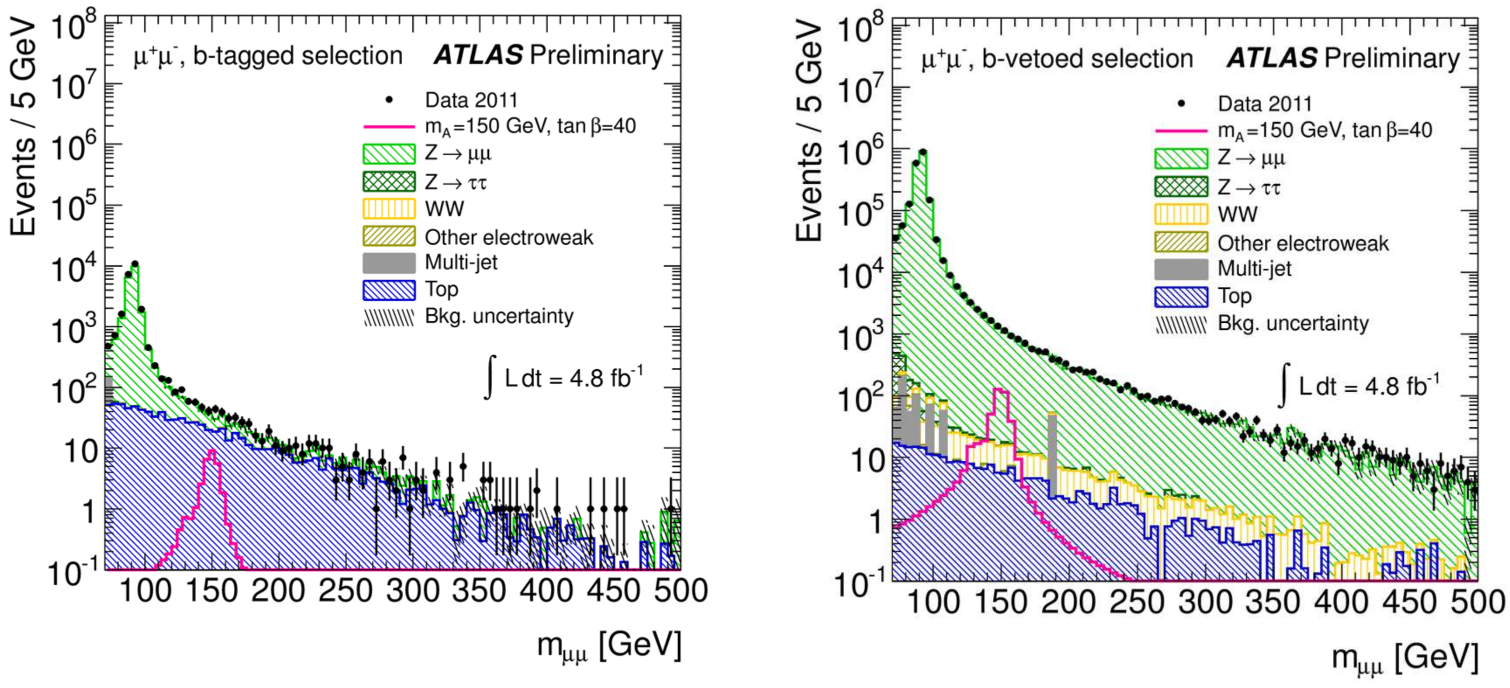

➔ Typical sensitivity for $m_A$=150 GeV: S/B~0.1

# MSSM Higgses (3)

ATLAS-CONF-2012-094

## ❑ Neutral Higgses : $\phi$=A/H/h → $\mu\mu$

- Main background : Z→$\mu\mu$ and Top
- Fitted from the side bands
- 2 type of Signal Regions to accommodate the 2 production modes: b-tagged or b-vetoed.

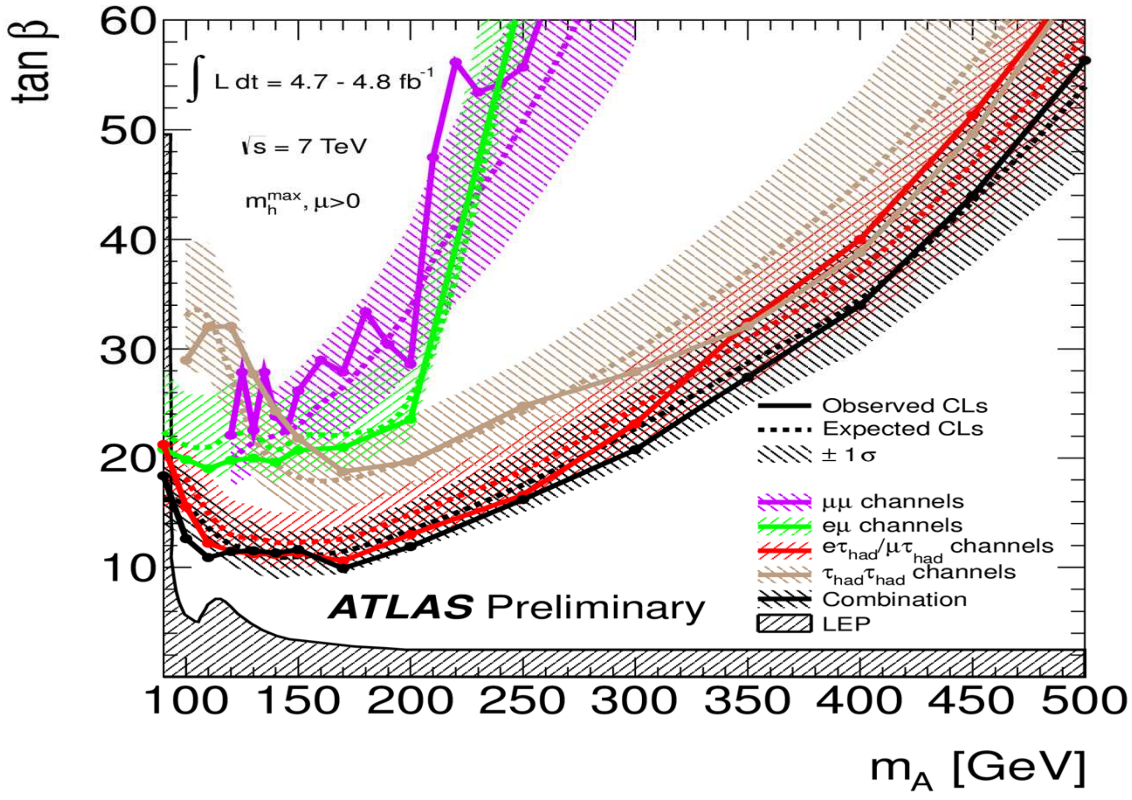



➔ Typical sensitivity for $m_A$=150 GeV: S/B~0.01

# MSSM Higgses (4)

ATLAS-CONF-2012-094

- **Combine all channels $\phi$=A/H/h → $\tau_{had}\tau_{had}$ , $\tau_{had}\tau_{lep}$ , $\tau_e\tau_\mu$, $\mu\mu$**
  - Put limits in a specific MSSM Model



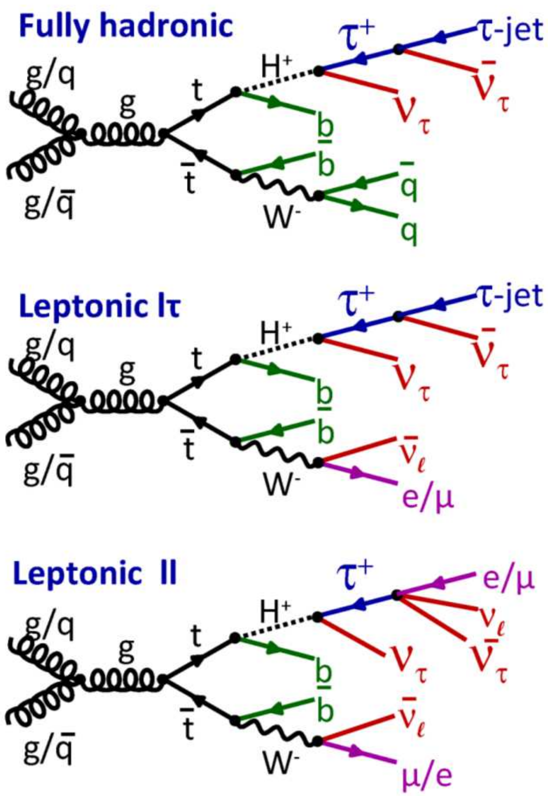

→ Dominated by $\tau_{had}\tau_{had}$ , $\tau_{had}\tau_{lep}$

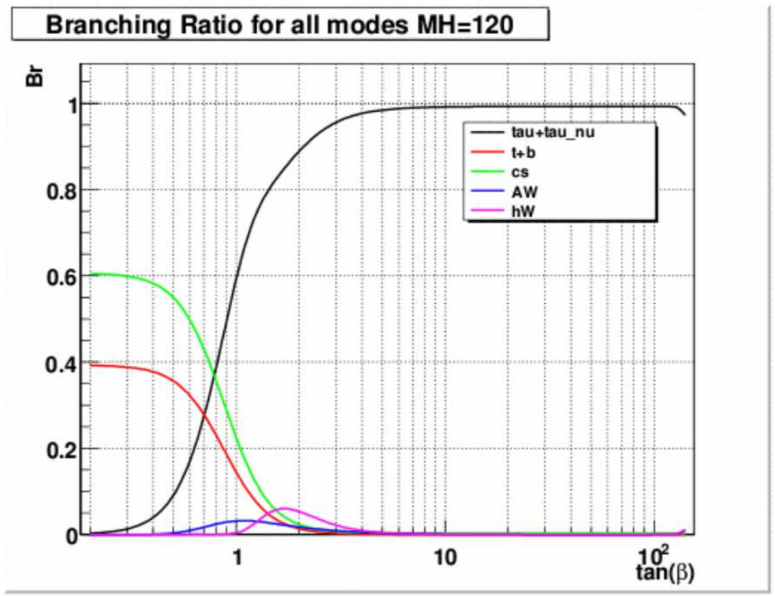
# MSSM Higgses (5)

arXiv:1204.2760

## ❑ Charged Higgs : $H^{+/-} \rightarrow \tau\nu$ (~100%)

- An elementary charged scalar particle : clearly indicate new physics beyond SM !
- Main production mode in the top quark decay $t \rightarrow bH^+$ : sensitivity below m(top)



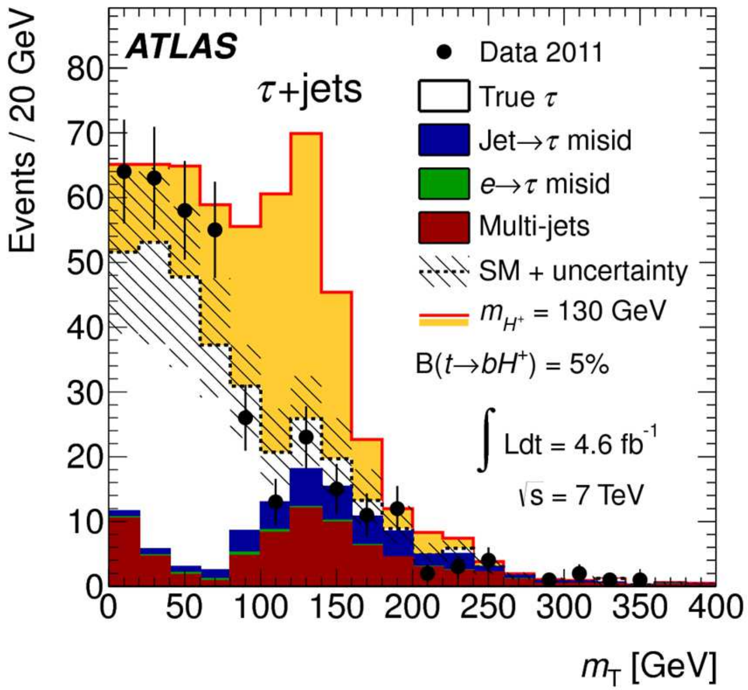



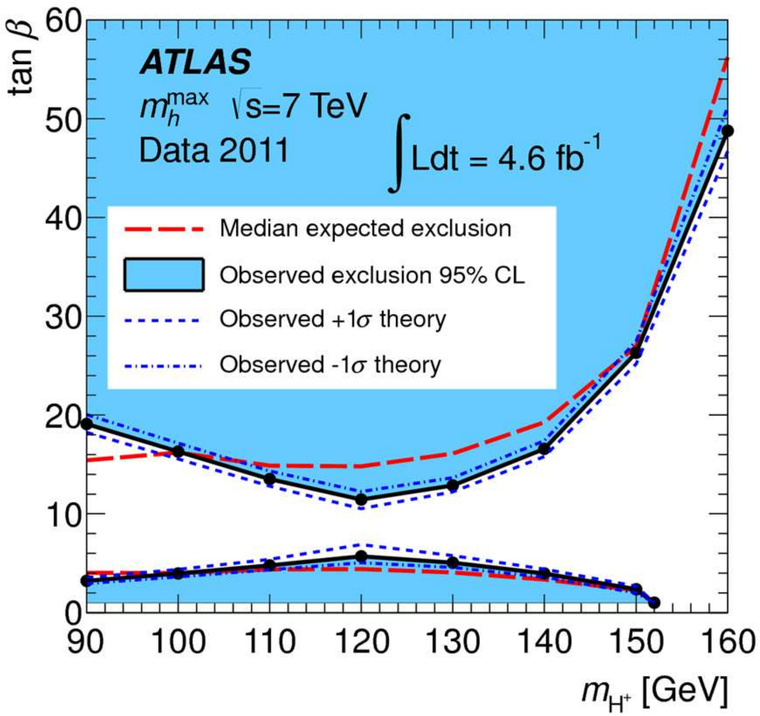
# MSSM Higgses (6)

arXiv:1204.2760

## ❑ Charged Higgs : $H^{+/-} \rightarrow \tau\nu$

- 3 channels: Fully hadronic (thad+W→jj), semi-leptonic (thad+W→lv), fully leptonic (tlep+W→lv)
- Main background ttbar
- Most powerful channel is fully hadronic



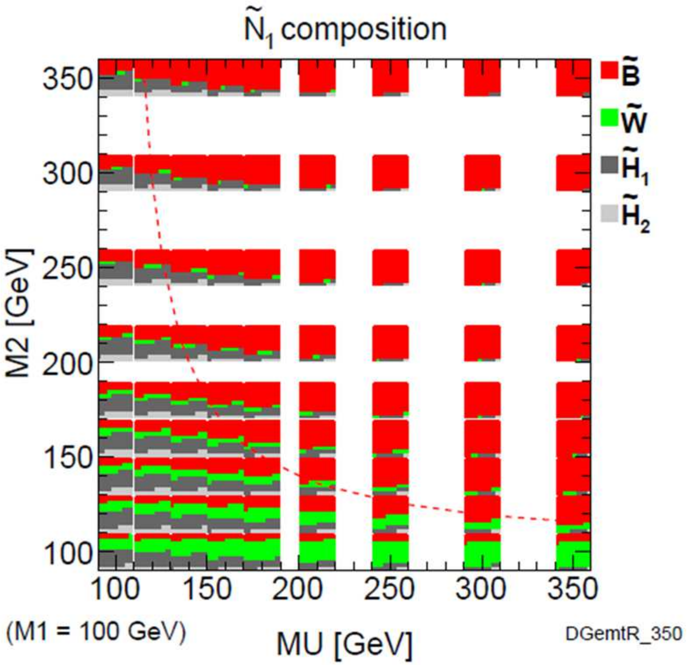

➔ Will close the plane at the end of 2012 (if no excess)

# Direct Gauginos in pMSSM

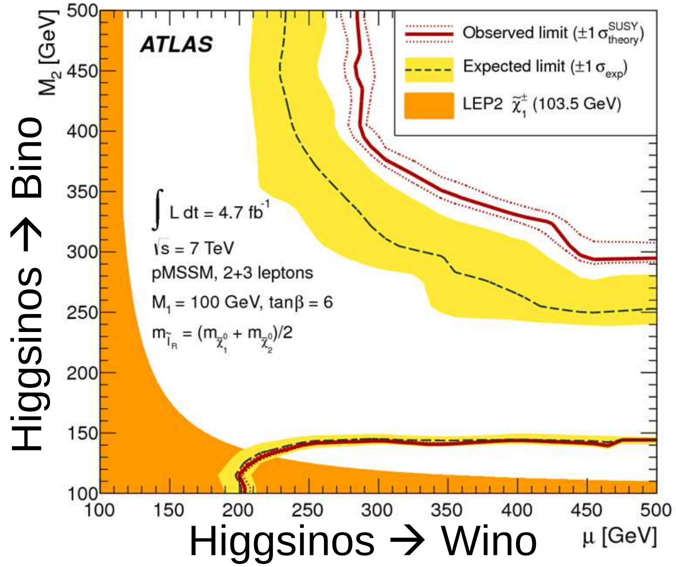
arXiv:1208.3144

## ❑ Closer to a real SUSY model ~pMSSM

- Mixing of eigenstates = f(M1 [Bino Mass], M2 [Wino masses], tanβ, μ [Higgses])
- Trilinear mixing all set to 0 except for the stop
- Combined 2lepton and 3leptons final states



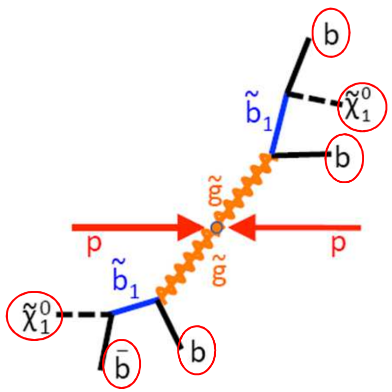

**M1=100 GeV, high mass splitting between $\chi_1^{\pm}$ and $\chi_1^0$ ➔ high Acc.**

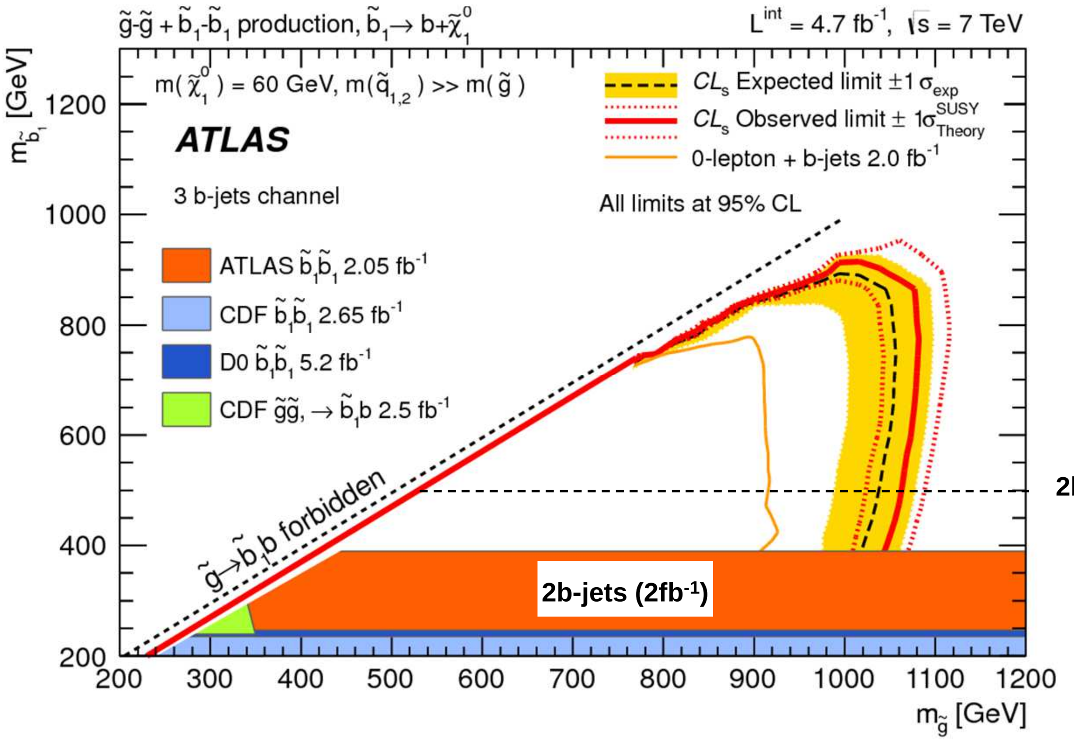


# Gluino Mediated Sbottom

arXiv:1207.4787

- **Final results at $\sqrt{s}$=7 TeV, 5 fb$^{-1}$**
  - 4 b-jets in the final states: 3b-jets analysis most competitive
  - Optimize the analysis for different b-tagging operating points



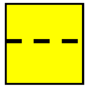

➔ Sensitive to $m_{\tilde{g}}$<1 TeV

# Exclusion limits

## ❑ Exclusion limits : a new standard ATLAS/CMS procedure (>June 2012)

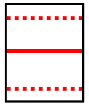
- Ease the life of theorist by separating the signal theoritical and experimental systematics

**Expected limit**:

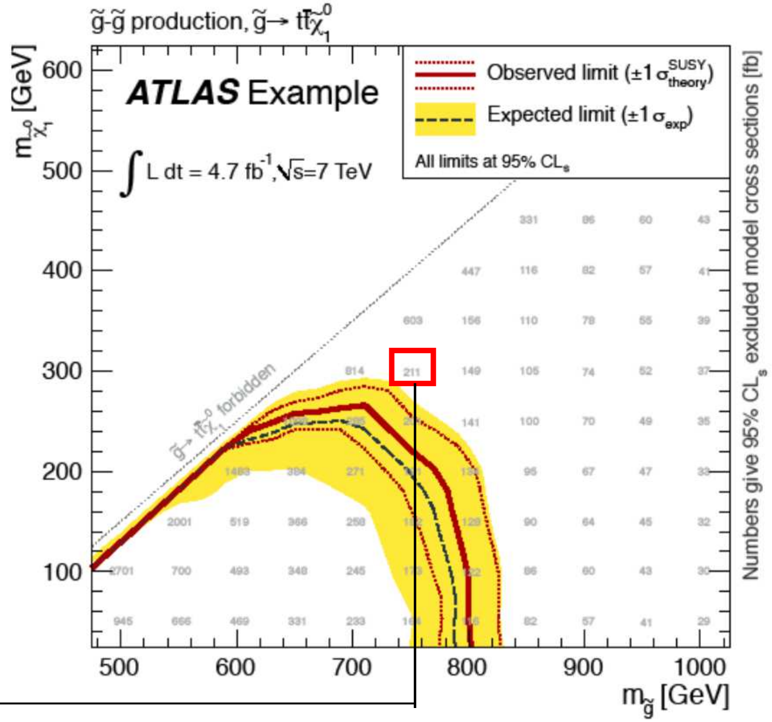


- **Central value:** all uncertainties included in the fit as nuisance parameters, except theoretical signal uncertainties (PDF,scales)
- **±1σ band** : ±1σ results of the fit

**Observed limit**:



- **Central value**: Idem as for expected limit
- **±1σ band** : re-run and increase/decrease the signal cross section by the theoretical signal uncertainties (PDF, scales)




**Excluded Model Cross section (SMS)**

➔ Number quoted in paper correspond to observed -1 σ observed (conservative)

# Result reinterpretation

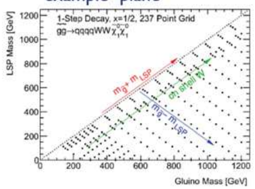
## Feel free to reinterpret our results !

- Acceptance, ε, CLs, … are provided for each analyses in HEPData

Refined and extended list of input to HEPdata, starting with winter 2012 results.

- Plots, interpretation (CLs limits) from paper and auxiliary material
- For each signal region, and for all relevant models
  - acceptance (A), defined next page [$A=N_{fiducial}/N_{total}$]
  - efficiency (ε), defined next page [$\varepsilon=N_{fiducial\text{-}reco}/N_{fiducial}$]
  - $\Delta^{tot}$ total systematic and theoretical signal uncertainty, not including MC stat. unc.
  - CLs value
- For all relevant models
  - Number of generated MC events (can be used to derive all signal MC stat. unc.)
  - $\sigma^{tot}$ total signal production cross section
  - SUSY Les Houches Accord (SLHA) files
- Relevant models:
  - E.g. small number of simplified models (easy kinematics)
  - no smoothing/interpolation between points

example "plane"



http://hepdata.cedar.ac.uk/

**The Durham HepData Project**

REACTION DATABASE | DATA REVIEWS | PARTON DISTRIBUTION FUNCTION SERVER | OTHER HEP RESOURCES

**Extra resource relating to the paper arxiv:1109.6572 - CERN-PH-2011-145**

Experimental acceptance/efficiency and excluded cross section*branching ratios:
Signal expectations and experimental acceptance/efficiency for M_gluino vs M_squark grid (massless LSP)
Signal expectations and experimental acceptance/efficiency for CMSSM/MSUGRA grid
SLHA files:
susy sqgl slha files
susy CMSSM/MSUGRA slha files

**Extra resource relating ot the ATLAS NOTE ATLAS-CONF-2011-155**

Experimental acceptance/efficiency and excluded cross section*branching ratio for M_gluino vs M_LSP grid:
(direct decays) - SHLA files
(one-step cascade decays, x=1/4) - SHLA files

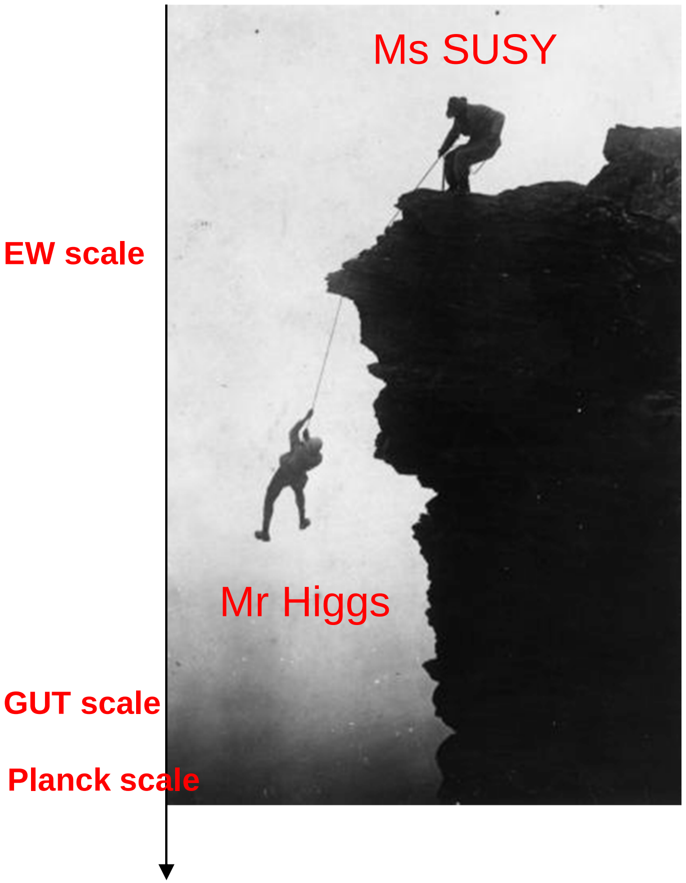
A user can probe his/her favorite model(s) by:

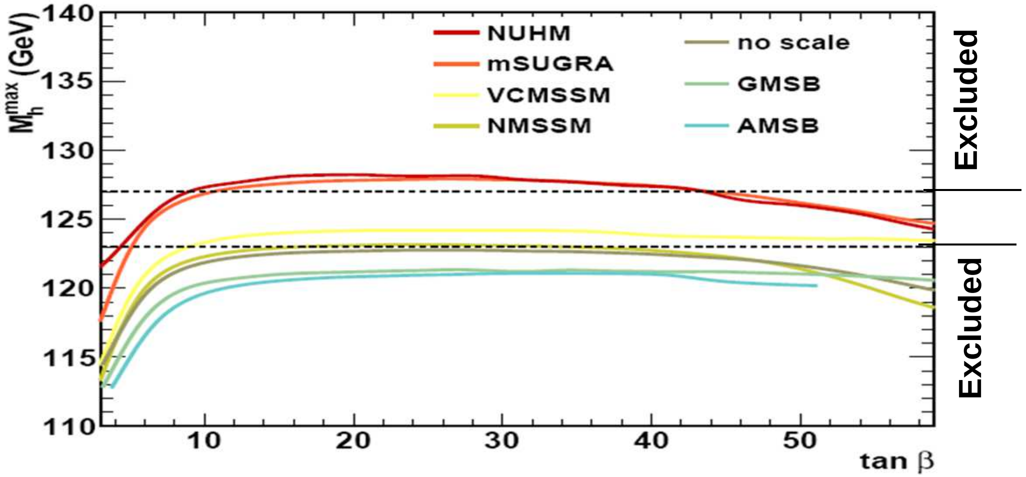
1. take our background estimate (per SR): $N^{tot} \pm \Delta^{tot}$ (numbers in publication)
2. implement event selection (per SR), validate against our acceptance numbers (in HEPdata)
3. implement a detector response, validate against our efficiency numbers (in HEPdata)
4. run on favorite model, and calculate sensitivity/limits using our visible upper limits (from publication)

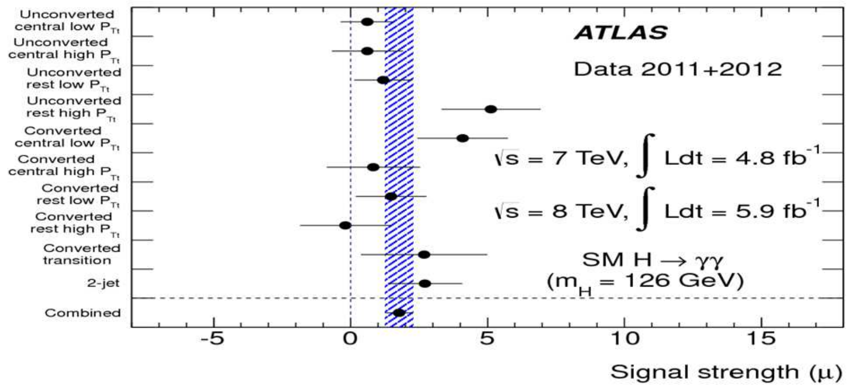
**More details: https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=173341**

# SUSY and the new boson

❑ **Higgs and (weak-scale) SUSY in close relation**



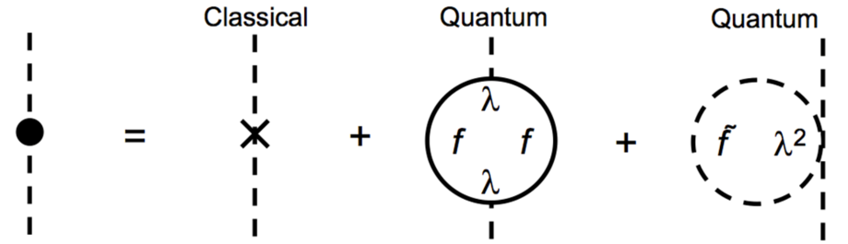




➔ Direct searches/"Higgs" properties (m, couplings) both powerfull to discover SUSY

# Why light stop mass ?

## ❑ SUSY and Naturalness

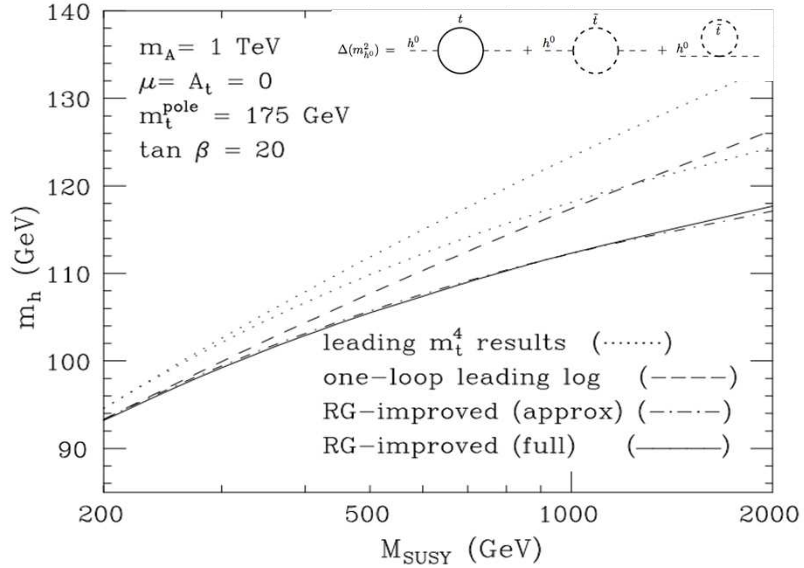



$$m_h^2 = (m_h^2)_0 - \underbrace{\frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2} + \frac{1}{16\pi^2}\lambda^2(m_{\tilde f}^2 - m_f^2)\ln(\Lambda/m_h)$$

**Small fine tuning ➔ light $\tilde{t}_1$**

## ❑ Radiative correction to $m_h$

$$m_{h^0}^2 = m_Z^2\cos^2(2\beta) + \frac{3}{4\pi^2}\sin^2\beta\, y_t^2\Big[m_t^2\ln\left(m_{\tilde t_1}m_{\tilde t_2}/m_t^2\right) + c_{\tilde t}^2 s_{\tilde t}^2(m_{\tilde t_2}^2 - m_{\tilde t_1}^2)\ln(m_{\tilde t_2}^2/m_{\tilde t_1}^2) + c_{\tilde t}^4 s_{\tilde t}^4\Big\{(m_{\tilde t_2}^2 - m_{\tilde t_1}^2)^2 - \frac{1}{2}(m_{\tilde t_2}^4 - m_{\tilde t_1}^4)\ln(m_{\tilde t_2}^2/m_{\tilde t_1}^2)\Big\}/m_t^2\Big].$$




**A 125 GeV $h^0$ ➔ heavy $\tilde{t}_1$**

➔ Some tension …

# Why light Higgsinos mass ?

## Light higgsinos

$$\mathcal{L}_{\text{MSSM}} = \mu \tilde{H}_u \tilde{H}_d + \text{h.c.} + (m_{H_u}^2 + |\mu|^2)\,|H_u|^2 + (m_{H_d}^2 + |\mu|^2)\,|H_d|^2 + \ldots$$

- Higgsino mass parameter $\mu$ is special: supersymmetric

  A priori $\mu$ is unrelated to the scale of SUSY breaking

- $\mu$ cannot be too small (LEP chargino bound: $m_{\chi_1^\pm} \gtrsim 100$ GeV)
- $\mu$ should not be too large:

$$m_Z^2 = -2\,m_{H_u}^2 - 2|\mu|^2 + \mathcal{O}(\cot^2\beta)$$

If $|m_{H_u}^2|, |\mu|^2 \gg m_Z^2 \Rightarrow$ large cancellation needed $\Rightarrow$ Fine-tuning!



## Light higgsinos

**Two approaches:**

- $\mu$ generated supersymmetrically, around EW scale by coincidence
- effective $\mu$ generated by SUSY breaking
  in calculable models: $\mu/B_\mu$ problem→ Giudice's talk $\Rightarrow$ $\mu$ still special

**Naturalness wants $\mu$ around 100 GeV:**

$$m_Z^2 = -2\,m_{H_u}^2 - 2|\mu|^2 + \mathcal{O}(\cot^2\beta)$$

**LHC bounds want squarks and gluinos above 1 TeV.**

Motivates studying scenarios where higgsinos are light (EW scale)
while everything else is heavy (multi-TeV) except maybe 3rd generation

**light higgsinos** = near-degenerate $\chi_1^0$, $\chi_1^\pm$, $\chi_2^0$ around 100–200 GeV

# Naturalness and New physics

G.F. Giudice (July 2012, LPCC Workshop @CERN)

1. Electron self-energy

electrostatic energy: $E \approx \frac{\alpha}{r} < m_e c^2 \Rightarrow \Lambda < \frac{m_e}{\alpha} \approx 70 \text{ MeV}$

magnetic energy: $E \approx \frac{\mu^2}{r^3}, \mu = \frac{e\hbar}{2m_e c} < m_e c^2 \Rightarrow \Lambda < \frac{m_e}{\alpha^{1/3}} \approx 3 \text{ MeV}$

New physics (positron) at $m_e = 0.5 \text{ MeV}$

2. Pion mass difference

QED contribution: $\frac{3\alpha}{4\pi}\Lambda^2 < M^2_{\pi^+} - M^2_{\pi^0} \Rightarrow \Lambda < 850 \text{ MeV}$

New physics (hadrons) at $M_\rho = 770 \text{ MeV}$

3. Neutral kaon mass difference

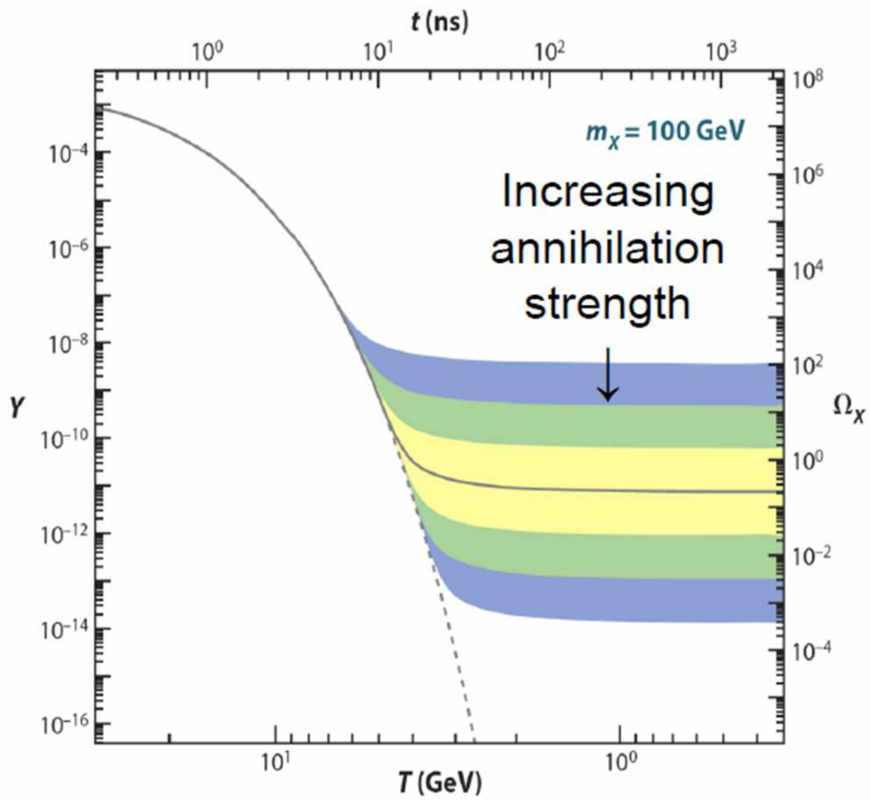
$$\frac{G_F^2 f_K^2}{6\pi^2} \sin^2\theta_c \Lambda^2 < \frac{M_{K_L^0} - M_{K_S^0}}{M_{K_L^0}} \Rightarrow \Lambda < 2 \text{ GeV}$$

New physics (charm) at $m_c = 1.2 \text{ GeV}$

The weak scale

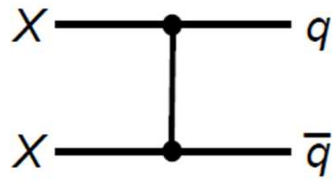
$$\delta m_h^2 = \frac{3G_F}{4\sqrt{2}\pi^2}\left(4m_t^2 - 2m_W^2 - m_Z^2 - m_h^2\right)\Lambda^2 < m_h^2 \Rightarrow \Lambda < 500 \text{ GeV}$$

# Dark Matter: The WIMP Miracle




- If you add a new particle to the Universe, the amount of it left over now is related to its annihilation cross section:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$




- $m_X \sim 100$ GeV, $g_X \sim 0.6 \rightarrow \Omega_X \sim 0.1$

- Remarkable coincidence: both particle physics and cosmology point to the 100 GeV scale for new particles

# Dark Matter: Effective operators

arXiv:1209.4625, 1210.4491

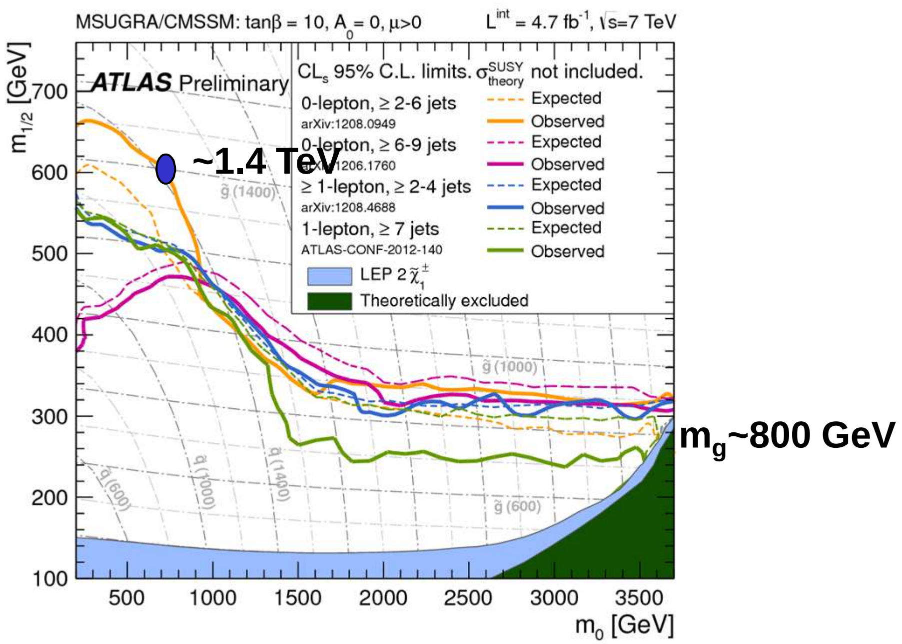
| Name | Initial state | Type | Operator |
|---|---|---|---|
| D1 | $qq$ | scalar | $\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$ |
| D5 | $qq$ | vector | $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$ |
| D8 | $qq$ | axial-vector | $\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$ |
| D9 | $qq$ | tensor | $\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$ |
| D11 | $gg$ | scalar | $\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$ |

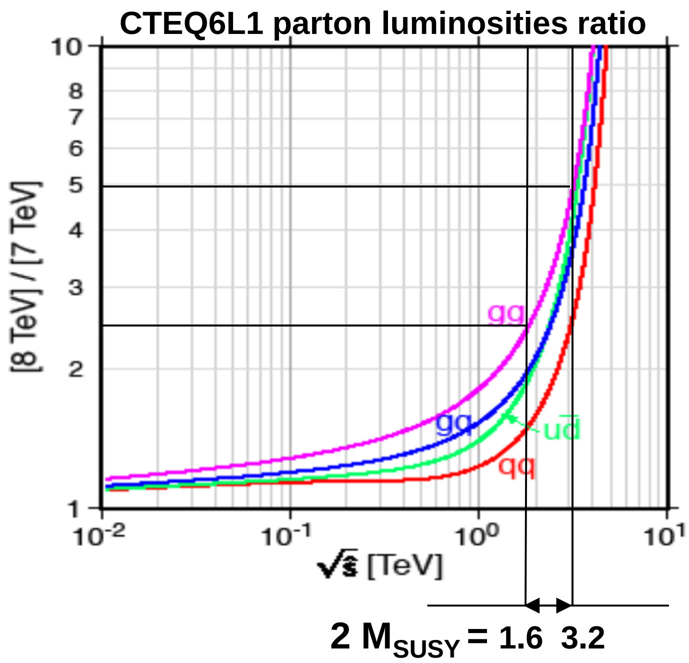
**Table 1**. Effective interactions coupling Dirac fermion WIMPs to Standard Model quarks or gluons, following the formalism of ref. [32]. The tensor operator D9 describes a magnetic-moment coupling. The factor of the strong coupling constant $\alpha_s$ in the definition of D11 accounts for this operator being induced at one-loop level. $G_{\mu\nu}$ is the colour field-strength tensor.

# 7TeV vs 8 TeV

## ❑ Status and outlooks on SUSY energy frontier search

- Exclude up to 1.4 TeV @ √s=7 TeV ($m_{\tilde{g}}=m_{\tilde{q}}$) ⬮ and $m_{\tilde{g}}$>800 GeV
- At the energy frontier √s=8 TeV can gain ~ 2.5-5 in parton luminosity wrt 7 TeV
  - ➔ Expect a sensitivity increase of few hundreds GeV




➔ Worth to look at √s=8 TeV with L(7 TeV) ~ L(8 TeV) !

# LHC 14 TeV Prospects (1)

## ❑ For energy frontier (gluinos, squarks)

- Extend $m_g$ by 100 GeV if $\sqrt{s}_{new}$ [TeV]= $\sqrt{s}_{orig}$ + 1 or $L_{new}$ [$fb^{-1}$]=$10xL_{orig}$

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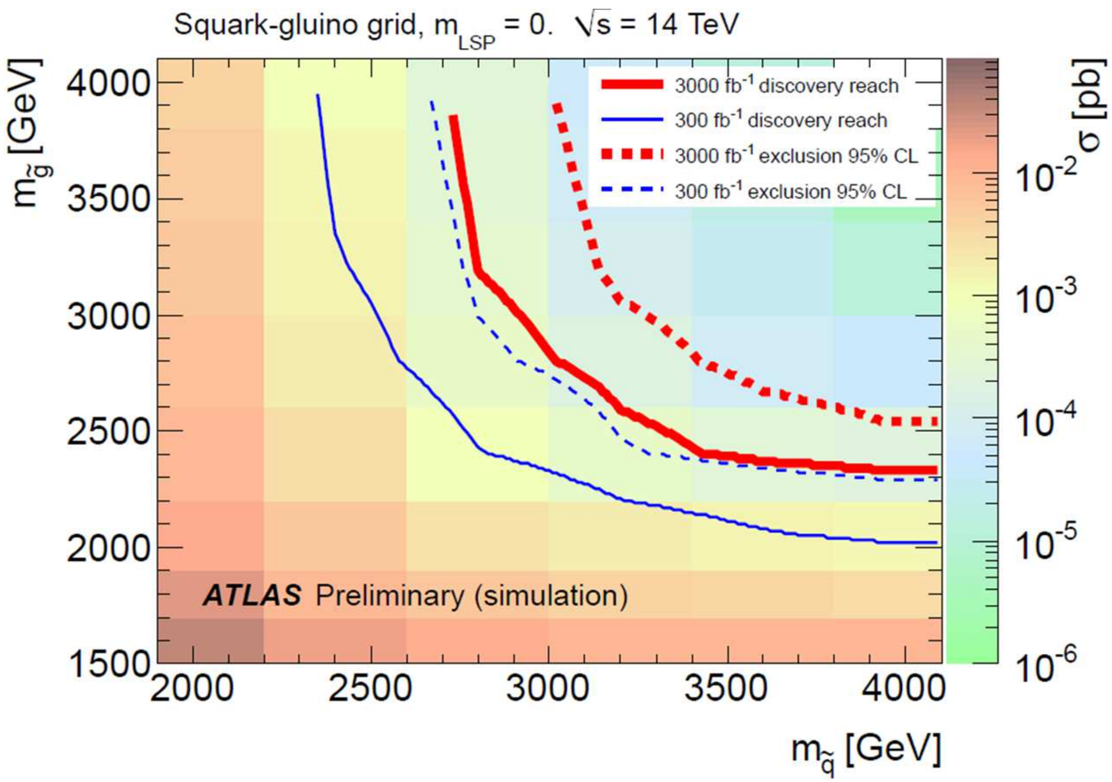


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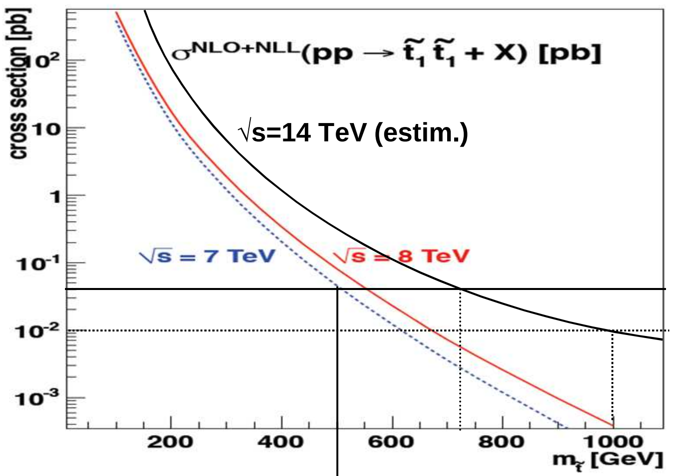
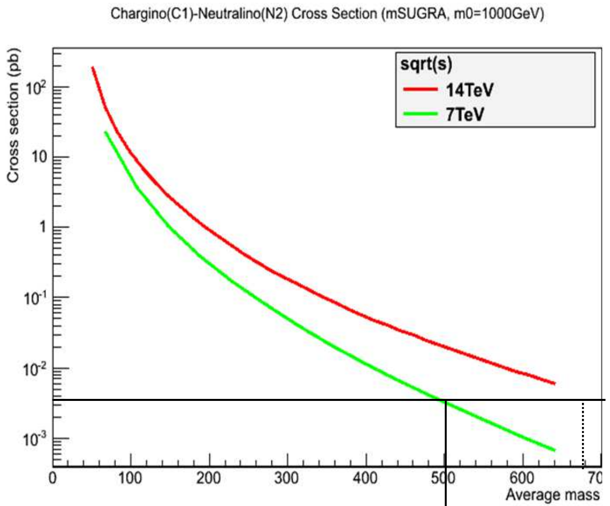
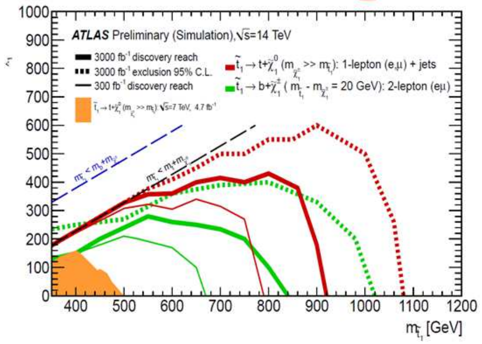
# LHC 14 TeV Prospects (2)

- **For stop / sbottom / gauginos below 1 TeV**
  - ➔ Generally ttbar main background : S/B constant vs $\sqrt{s}_{new}$ but $S/\sqrt{B}$ increases

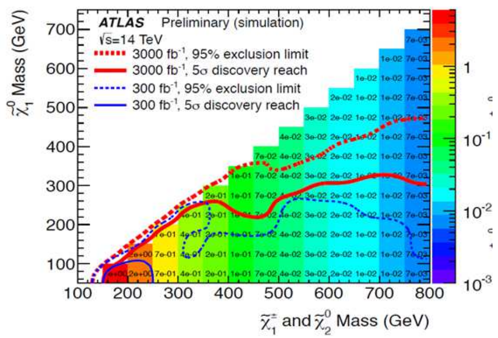



**Limit for M(LSP)=0 @ 5 fb$^{-1}$**




**Limit for M(LSP)=0 @ 5 fb$^{-1}$**

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