# Search for Supersymmetry in the ATLAS Experiment

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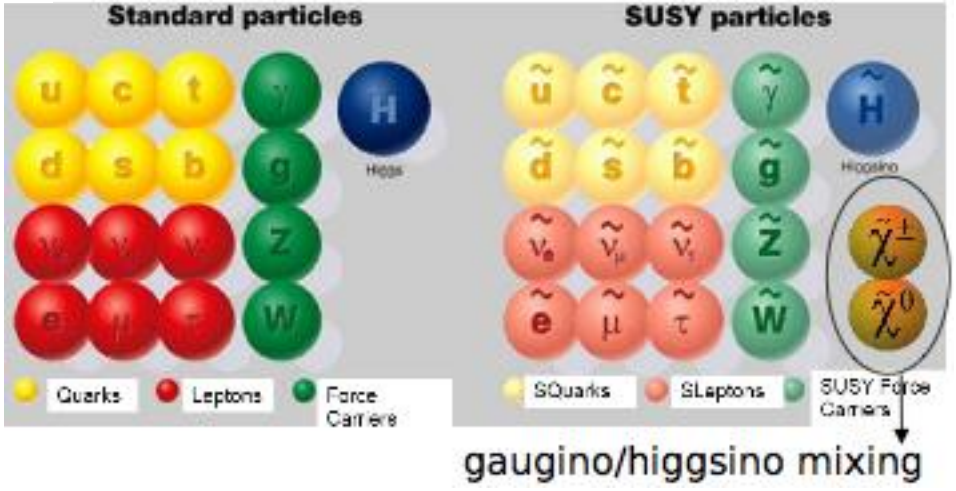
# Introduction

- Why Supersymmetry? Provides solution to the following problems the Standard Model (SM) has:
  - Gravity is not yet incorporated
  - Hierarchy/naturalness problem
  - Lack of unification of couplings
  - Dark matter problem
- Minimal Supersymmetric Standard Model (MSSM)
  - A superpartner for each SM particle, 5 Higgs bosons
  - 105 parameters. Minimal flavor violation -> 19 parameters
  - If R parity conserved: $R=(-1)^{3(B-L)+2S}$

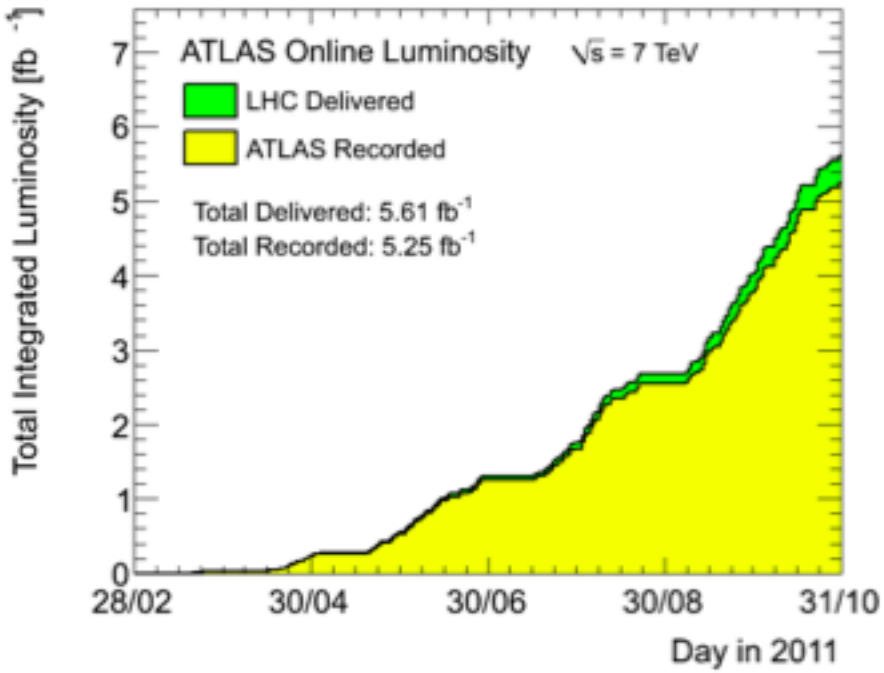
  - SUSY particles pair produced
  - LSP (Lightest SUSY particle) stable
- SUSY is broken, SUSY breaking

defines the phenomenology: mSUGRA, GMSB, AMSB, …



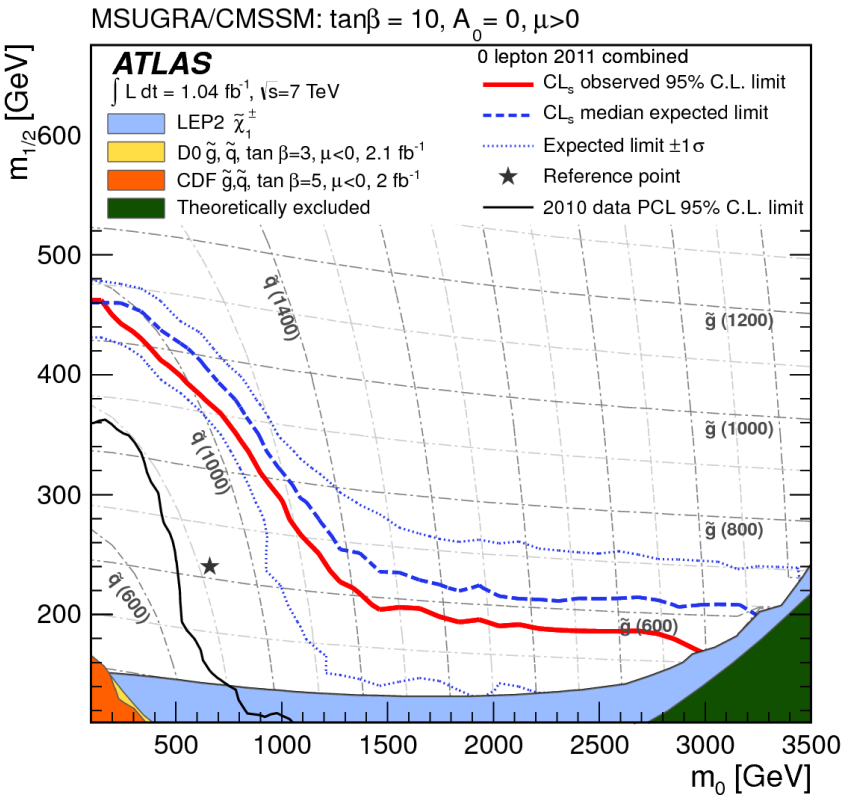
# 2011 Data Taking

- Highest luminosity = $3.65 \cdot 10^{33}$ $cm^{-2}s^{-1}$
- Total Collisions = $350 \cdot 10^{12}$= 350000000000000
- Recorded luminosity = 5.257 $fb^{-1}$




Excellent detector performance

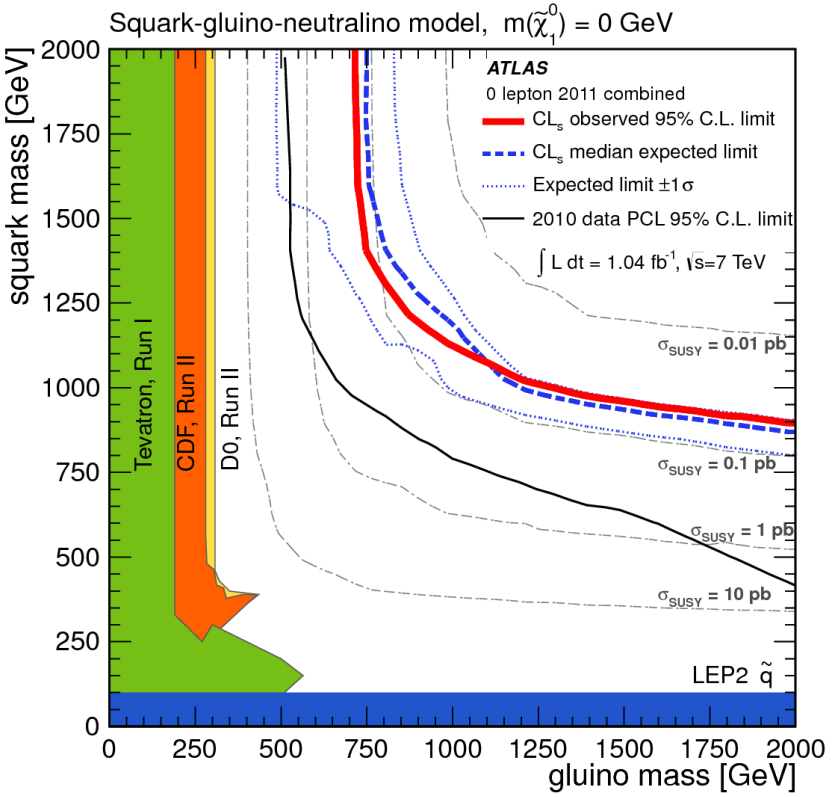
# 0-lepton Channel




arXiv:1109.6572, 1.04 fb$^{-1}$

Search channel: jets + Etmiss + no leptons

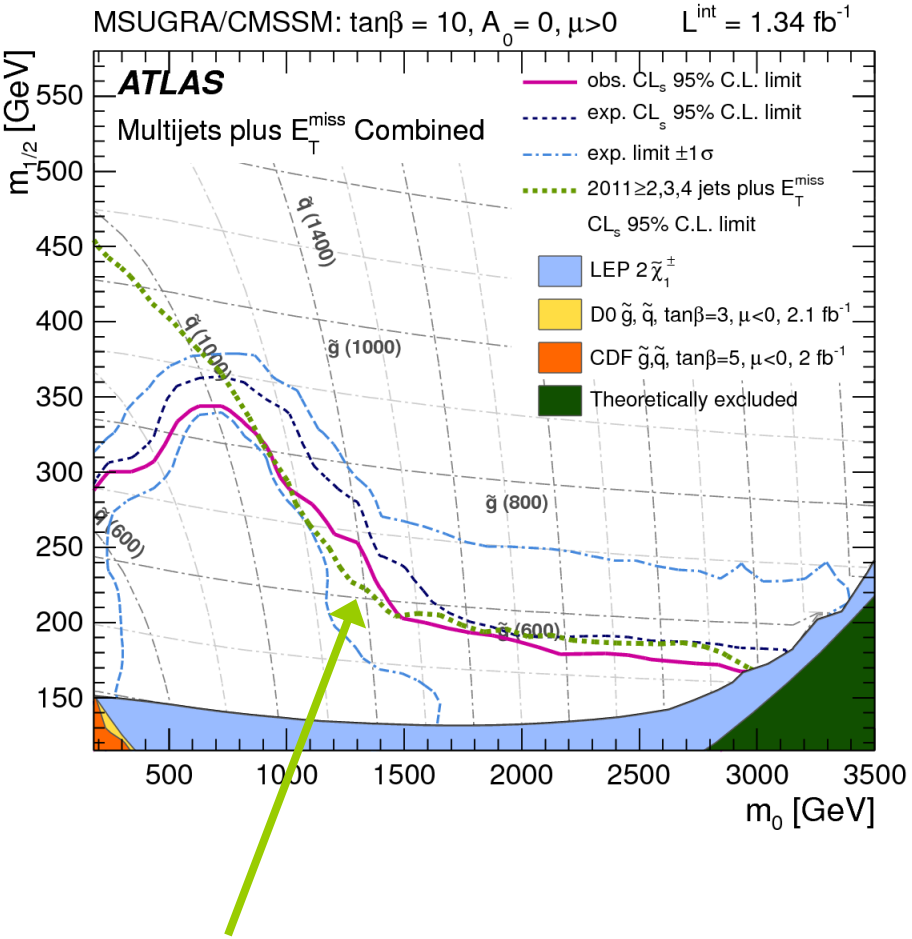
**MSUGRA/CMSSM model:** gluinos with masses below 950 GeV are excluded at 95% CL.




**Simplified models**: gluino and squark masses below 700 GeV and 875 GeV respectively excluded for gluino or squark masses below 2 TeV. The limit increases to 1075 GeV for equal mass gluinos and squarks.
**Additional model interpretations**: Simplified models with massive neutralino LSP. Minimal Universal Extra Dimensions model. ATLAS-CONF-2011-155

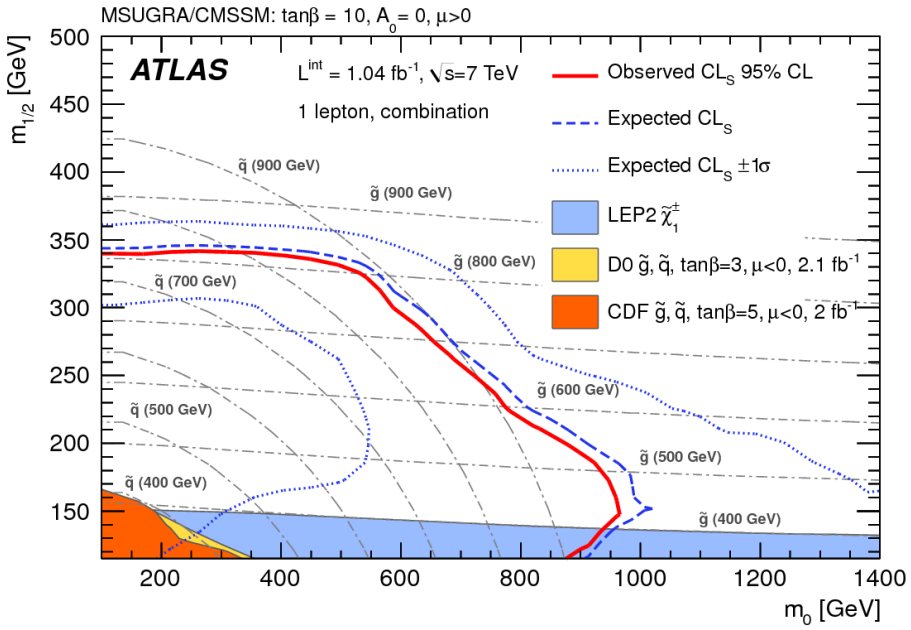
# Multi-jets Channel

- arXiV:1110.2299, 1.34 fb$^{-1}$
- Search channel: at least 6, 7 or 8 jets + Etmiss + no lepton
- Increase sensitivity to models with many-body decays.
- SUSY models with gluinos with masses near the TeV scale and relatively heavy squarks.
- **MSUGRA/CMSSM model:**
  - For equal squark and gluino masses, masses below 520 GeV are excluded.
  - For m(squark) = 2 x m(gluino), gluinos with masses below 680 GeV are excluded.




**0-lepton channel**

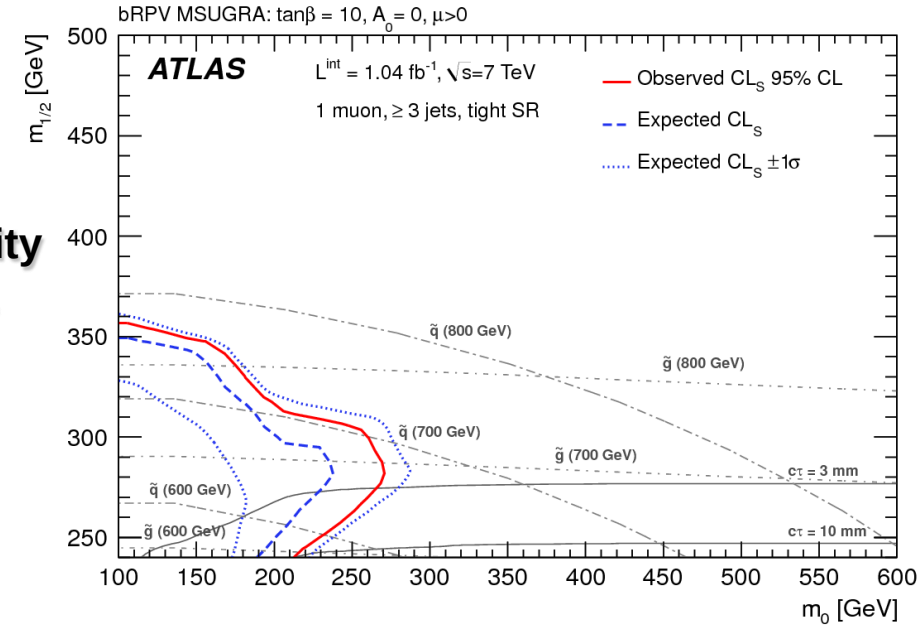
# 1-lepton Channel




arXiv:1109.6606, 1.04 fb$^{-1}$

Search channel: jets + Etmiss + 1 isolated lepton

**MSUGRA/CMSSM model:** for equal squark and gluino masses, masses below 820 GeV are excluded.




**Supersymmetric models with bilinear R-parity violation:** for equal squark and gluino masses, masses below 760 GeV are excluded.

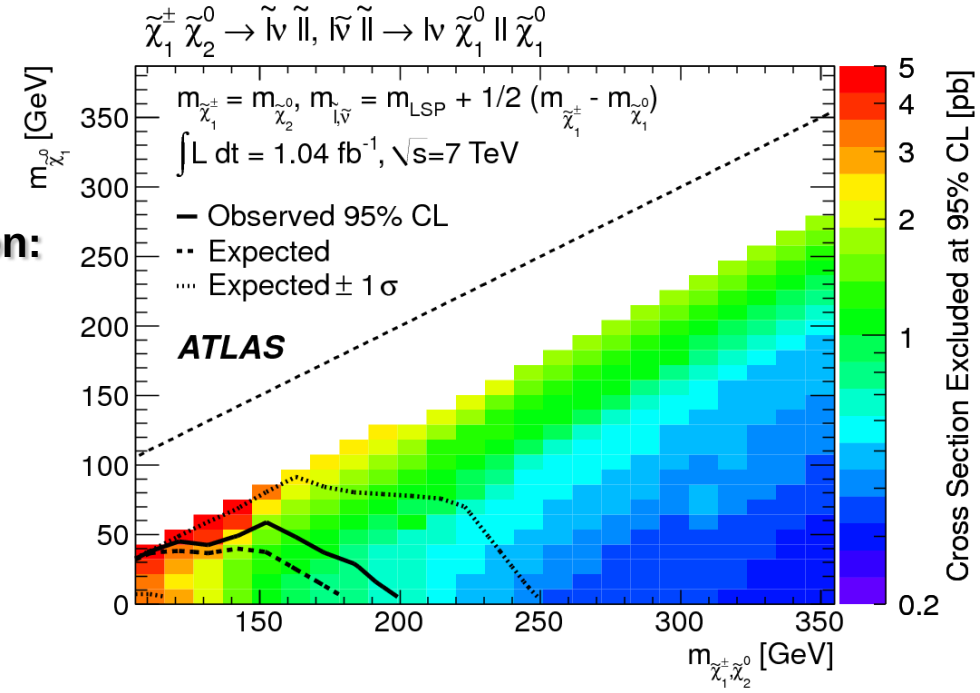
See also arXiv paper for limits set within Simplified Models.

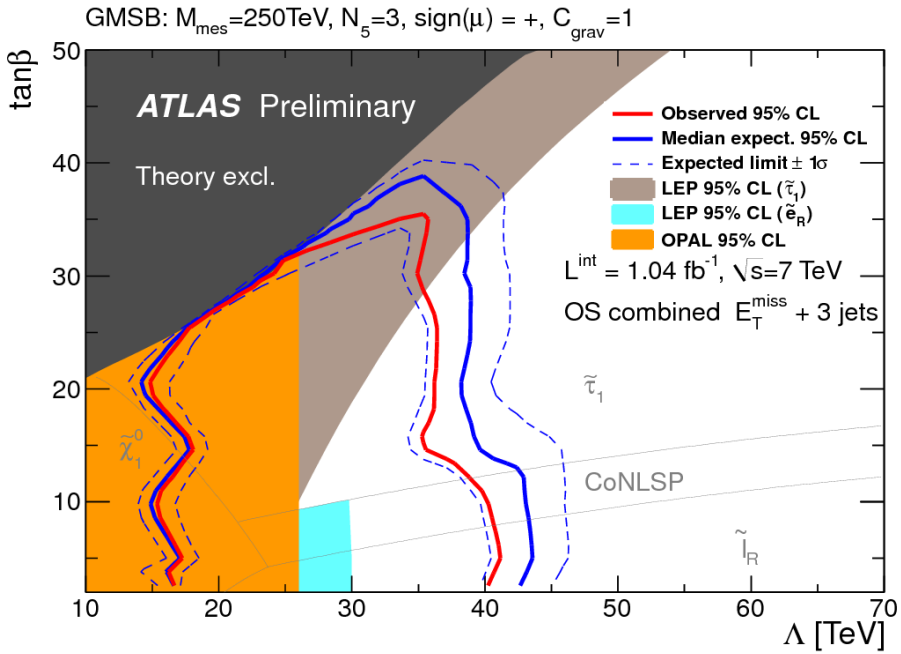
# 2-lepton Channel

arXiV:1110.6189, 1.04 fb$^{-1}$

Search channel: jets+Etmiss+2 isolated lepton

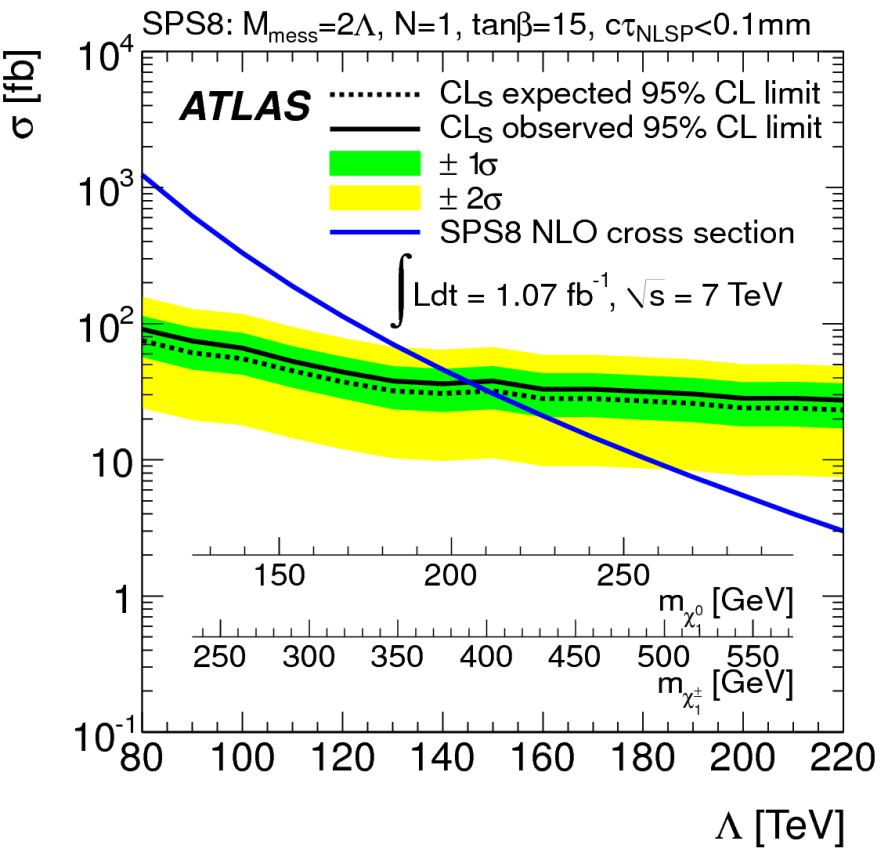
**Simplified model of direct gaugino production:**
In same sign dilepton channel, charginos with masses below 200 GeV are excluded.




ATLAS-CONF-2011-156
GMSB model interpretation

# 2-photon Channel

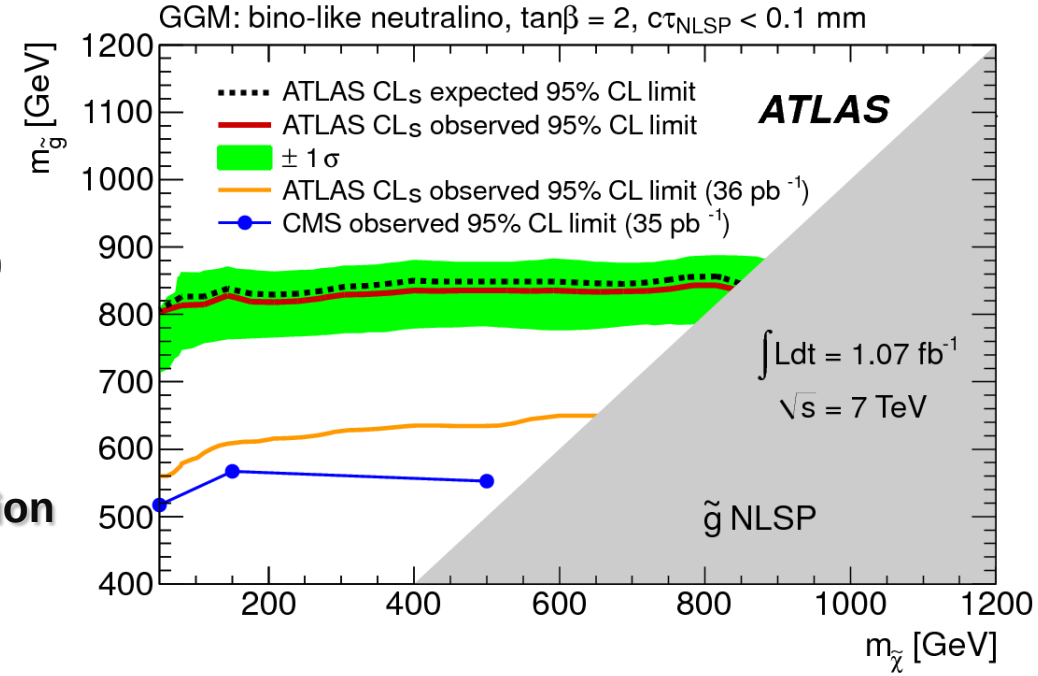



arXiv:1111.4116, 1.07 fb$^{-1}$

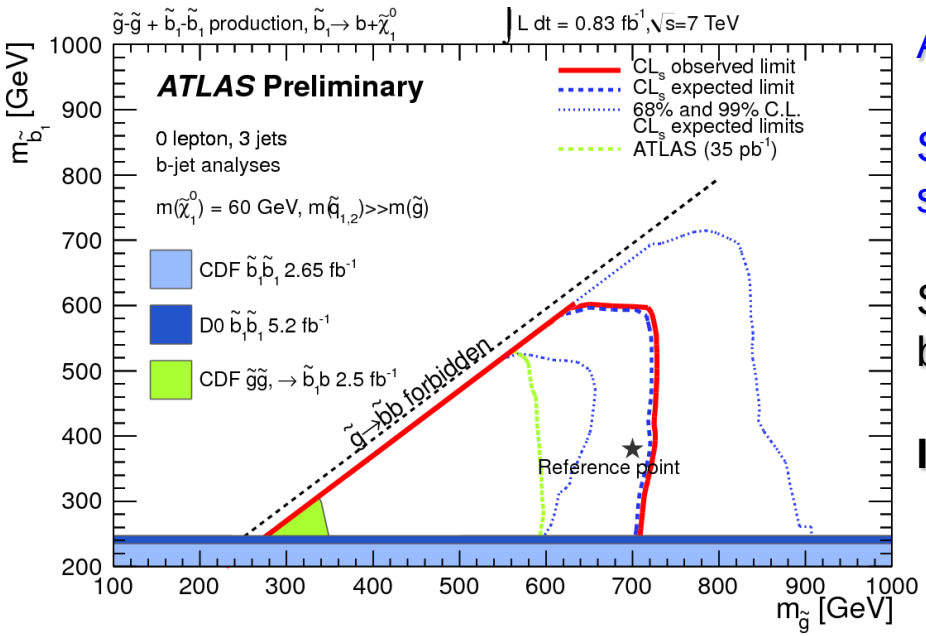
Search channel: 2 isolated photons + Etmiss

**Minimal Gauge Mediation model interpretation**

**General Gauge Mediation model interpretation**



# b-jet Channel (with 0-lepton)

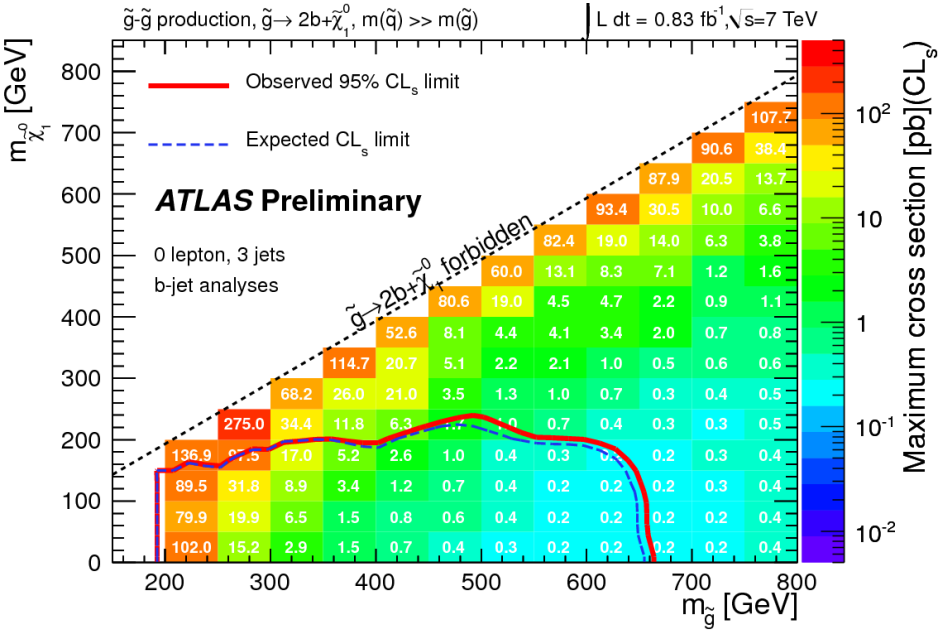



ATLAS-CONF-2011-098, 0.83 fb$^{-1}$

Search for 3rd generation squarks via stops and sbottoms in gluino decays

Search channel: at least 3 jets (at least one b-tagged) + Etmiss + 0 lepton

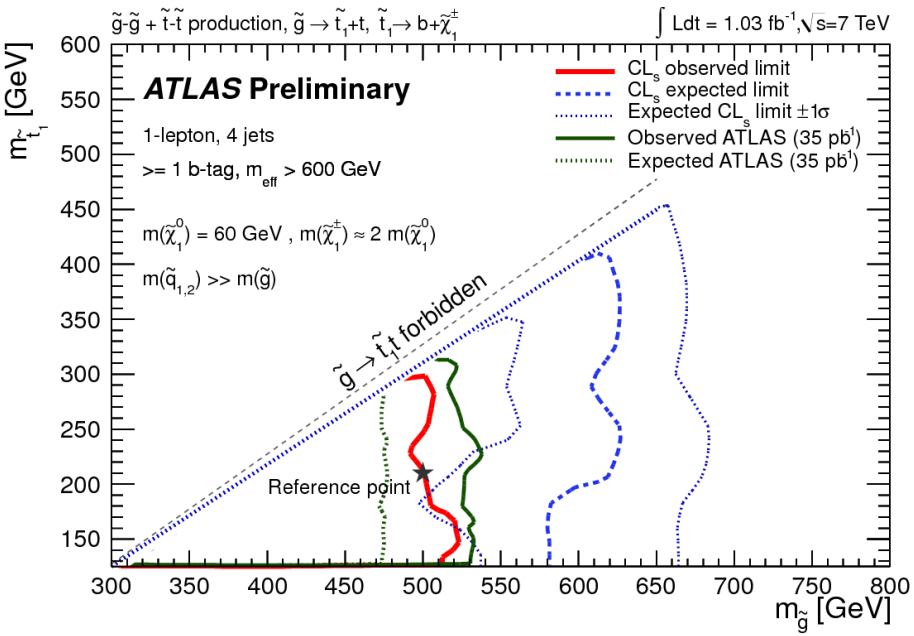
**Interpretation: gluino -> sbottom + bottom**




**Interpretation: gluino -> 2 bottom + LSP**

**Results updated to 2.05 fb$^{-1}$, however not yet public**

# b-jet Channel (with 1-lepton)

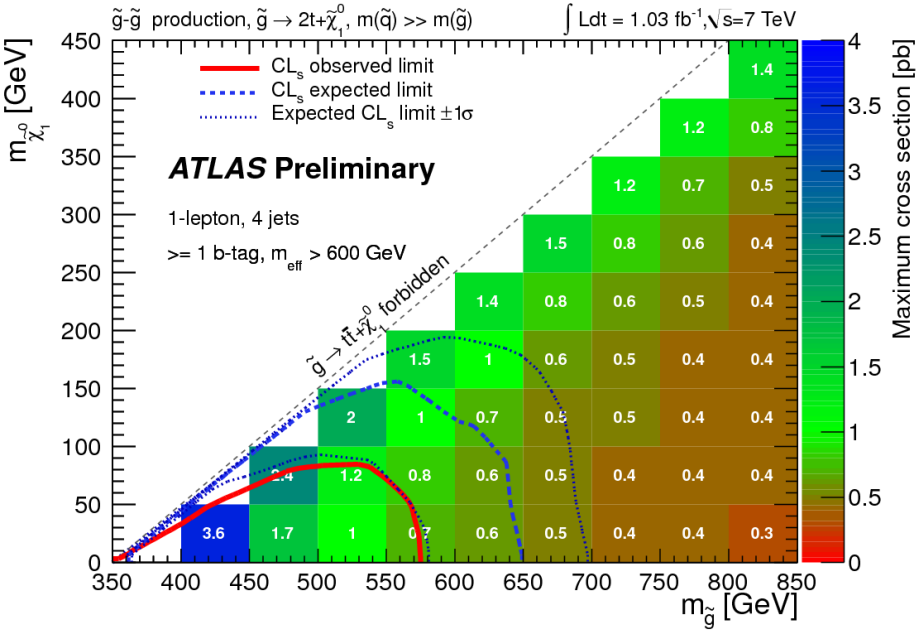



ATLAS-CONF-2011-130, 1.03 fb$^{-1}$

Search for 3rd generation squarks via stops and sbottoms in gluino decays

Search channel: at least 4 jets (at least one b-tagged) + Etmiss + 1 isolated lepton

**Interpretation: gluino -> stop (->b+χ)+ top**



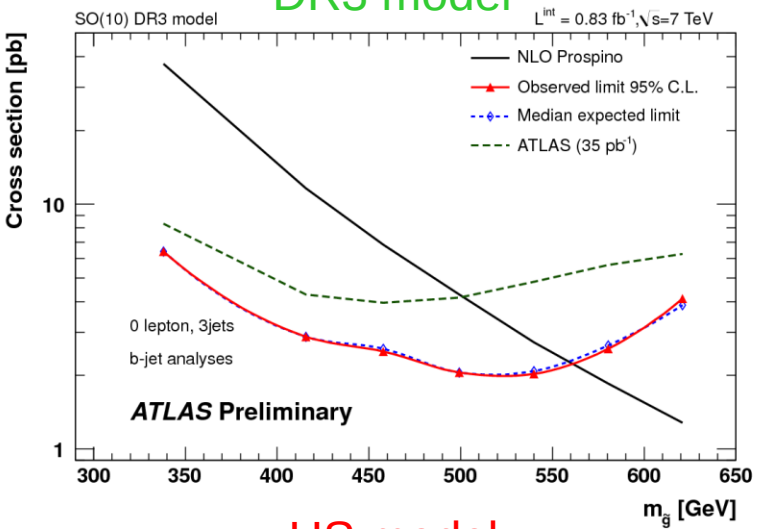

**Interpretation: gluino -> 2 top + LSP**

**Results updated to 2.05 fb$^{-1}$, however not yet public**

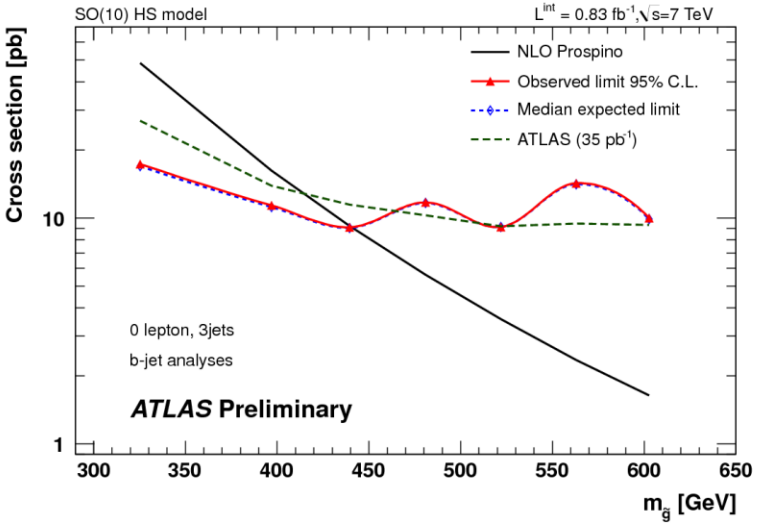
# b-jet Channel (with 0-lepton) – Search for SO(10) SUSY

- ATLAS-CONF-2011-098, 0.83 $fb^{-1}$
- Motivation: Yukawa-unified SO(10) SUSY GUT models are compelling models offering light gluinos with ~300-600 GeV.
- SUSY events: gluino pair production followed by 3-body decays to b-jets.
- Two model lines: DR3 model - gluinos with masses below 570 GeV are excluded. HS model– gluinos with masses below 450 GeV excluded.
- Results updated to 2.05 $fb^{-1}$, however not yet public.

DR3 model



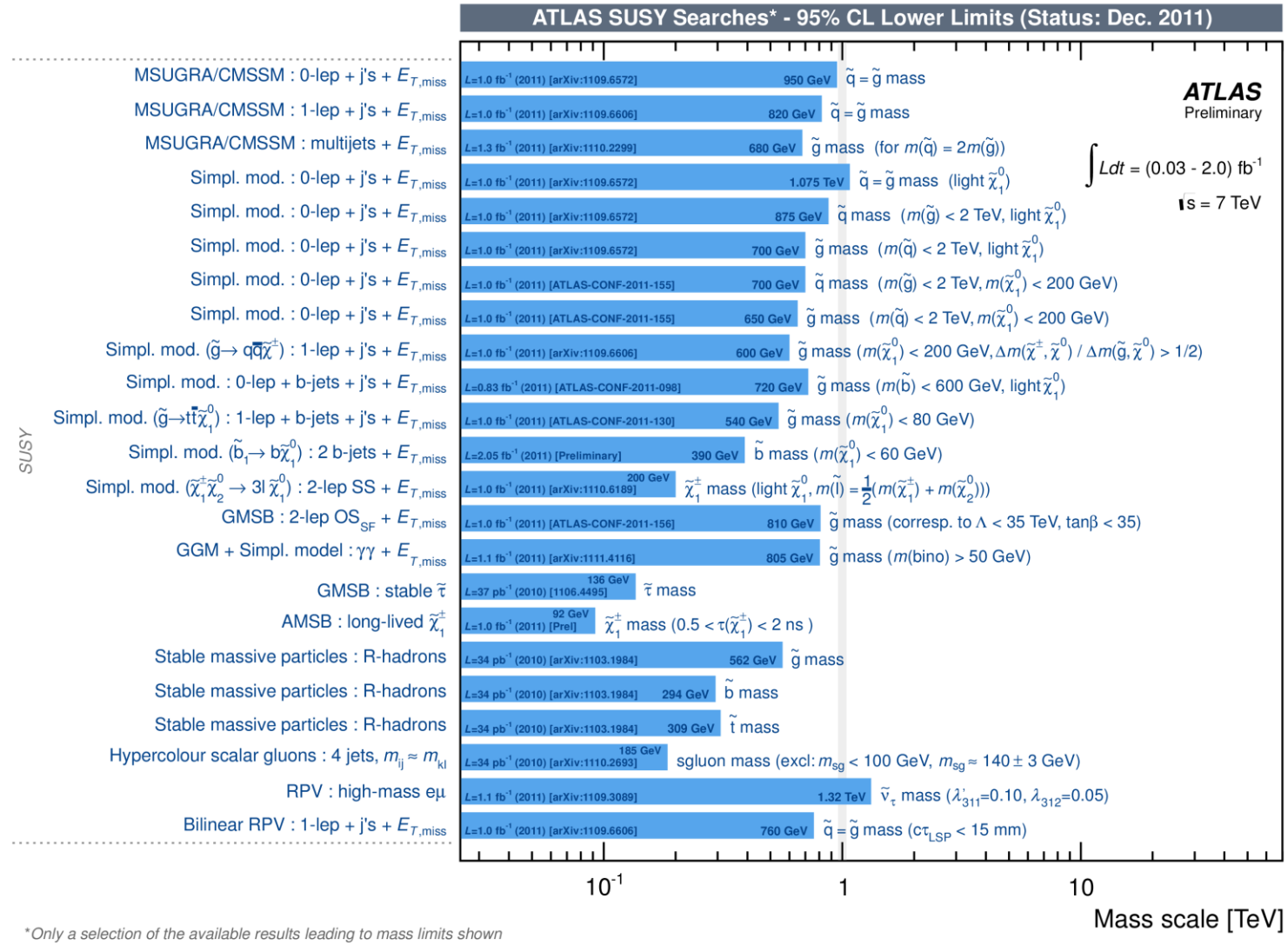

HS model



# Other Searches

- Search for 3rd generation squarks – major motivation for SUSY at low energies
  - Direct sbottom pair production – arXiv:1112.3832, 2.05 $fb^{-1}$
  - Direct stop pair production - arXiv:1109.4725, 1.04 $fb^{-1}$
- Trileptons - ATLAS-CONF-2011-039, 34 $pb^{-1}$, update to 2011 data in pipeline
- Special final states:
  - Resonant sneutrino - R-parity violation – arXiv:1109.3089, 1.07 $fb^{-1}$
  - Disappearing tracks – search for AMSB, 1.02 $fb^{-1}$
  - Displaced vertex – R-parity violation - arXiv:1109.2242, 33 $pb^{-1}$
  - Long-lived particles:
    - arXiv:1103.1984, 34 $pb^{-1}$
    - arXiv:1106.4495 37 $pb^{-1}$

# Summary: Mass reach of ATLAS SUSY searches




*Only a selection of the available results leading to mass limits shown

# Is SUSY Still Alive?

SUSY still well alive,
since no hard info, yet, on the crucial configuration

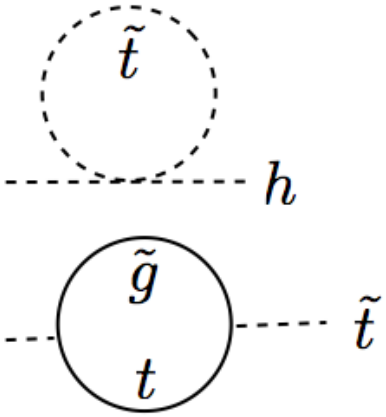
The key equations:

$$\frac{m_h^2}{2} \approx -|\mu|^2 + m_u^2$$

$$\delta m_u^2 \approx -\frac{3y_t^2}{8\pi^2}(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + A_t^2)\log M/m_{\tilde{t}}$$

$$\delta m_{\tilde{t}}^2 \approx \frac{8\alpha_s}{3\pi} m_{\tilde{g}}^2 \log M/m_{\tilde{t}}$$

$m_{\tilde{h}}$, $m_{\tilde{b}_L}$, $m_{\tilde{g}}$




R. Barbieri
2011 HCP

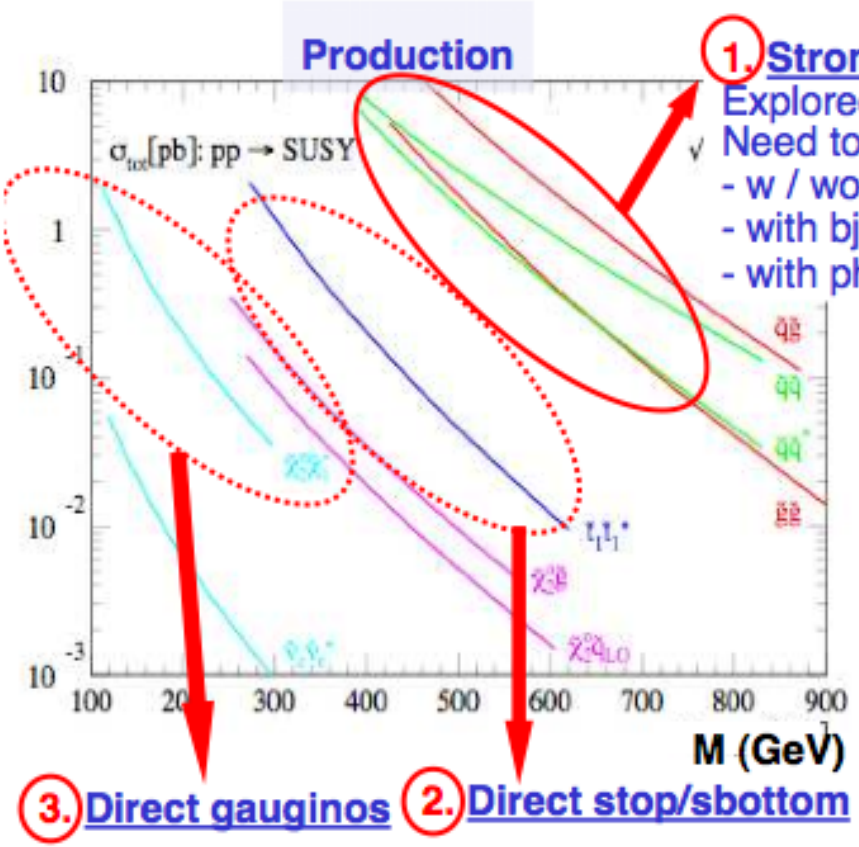
(to be made more precise in any given SB-mediation scheme)

see, e.g., Dimopoulos, Giudice for SUGRA-mediation, 1995

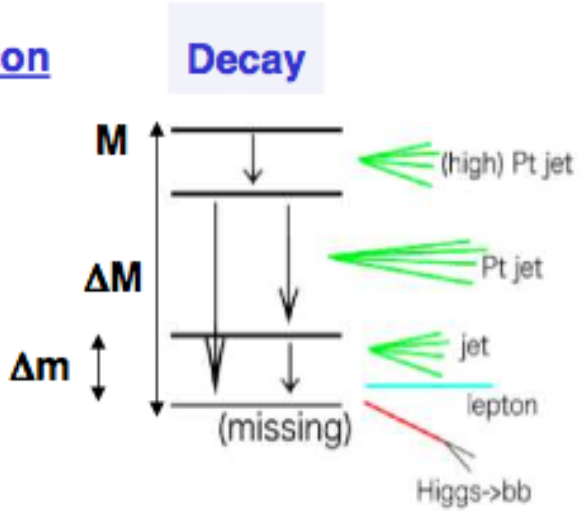
All s-particles other than $\tilde{g}, \tilde{t}_L, \tilde{t}_R, \tilde{b}_L, \tilde{h}$ weakly constrained

# Conclusions

❑ **SUSY is not dead (exp. view) : still lot of phase space to explore (M, ΔM, Δm)**




1. **Strong production**
Explored heavily …
Need to continue:
- w / wo leptons
- with bjet(s)
- with photons




4. **High DM/M explored.** Focus also on low DM/M *(compressed spectra)*

5. **RPV signatures:** lower Etmiss (no LSP), resonances, multijets, multileptons

6. **Almost Degenerate case (low Δm):** Long Lived particle, displaced vertex, kinked track

Please tune for ATLAS SUSY results at:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

# Backup Slides

# 0-lepton Channel – Signal regions

Search channel: final states with jets+Etmiss+no leptons

| Signal Region | ≥ 2-jet | ≥ 3-jet | ≥ 4-jet | High mass |
|---|---|---|---|---|
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | > 130 | > 130 | > 130 | > 130 |
| Leading jet $p_{\mathrm{T}}$ | > 130 | > 130 | > 130 | > 130 |
| Second jet $p_{\mathrm{T}}$ | > 40 | > 40 | > 40 | > 80 |
| Third jet $p_{\mathrm{T}}$ | – | > 40 | > 40 | > 80 |
| Fourth jet $p_{\mathrm{T}}$ | – | – | > 40 | > 80 |
| $\Delta\phi(\mathrm{jet}, \vec{P}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ | > 0.4 | > 0.4 | > 0.4 | > 0.4 |
| $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$ | > 0.3 | > 0.25 | > 0.25 | > 0.2 |
| $m_{\mathrm{eff}}$ | > 1000 | > 1000 | > 500/1000 | > 1100 |

# Simplified Models

The simplified models by construction reduce the supersymmetric parameter space to a maximum of three free parameters, from the list below:

1. The mass of the degenerate first- and second-generation squarks, $m_{\tilde{q}}$.
2. The mass of the gluino, $m_{\tilde{g}}$.
3. The mass of the neutralino LSP, $m_{\tilde{\chi}_1^0}$.
4. The parameter $x$, defined as

$$x = \frac{m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}}{m_{\tilde{q}_L,\tilde{g}} - m_{\tilde{\chi}_1^0}}, \qquad (1)$$

which controls the mass of the lighter chargino relative to the squark or gluino and the LSP.

# Yukawa-unified SO(10) SUSY Model

- Motivation: Yukawa-unified SO(10) SUSY GUT models are compelling models offering an early SUSY discovery. Light gluinos with ~300-600 GeV.
  - Paper by Howard Baer etal, JHEP 1002:055,2010. arXiv:0911.4739 [hep-ph].
- Model proposed to SUSY Working Group by N. Ozturk. Prepared Monte Carlo samples. Work in collaboration with P. Skubic and A. Marzin (Univ. of Oklahoma).
- SO(10)-inspired SUSY parameter space:
  - $m_{16}$ : common mass of all scalars at $M_{GUT}$
  - $m_{1/2}$ : common GUT scale gaugino mass
  - $A_0$ : common GUT scale trilinear soft term
  - tan($\beta$) : the ratio of Higgs field vevs
  - sign($\mu$) : sign of superpotential Higgs mass $\mu$
  - m(top): top quark mass
  - Higgs soft masses at GUT scale: $m^2_{H_{u,d}} = m^2_{10} \pm 2M^2_D$
- $m_{10}$ : common mass for Higgs scalars at $M_{GUT}$
- $M^2_D$ : parametrizes either D-term splitting (DR3 model) or Higgs-only (HS model) soft mass splitting

# SO(10) SUSY Mass Spectra

- Scan parameter space to search for Yukawa-unified solutions.
- Examine $R=\max(f_t, f_b, f_\tau)/\min(f_t, f_b, f_\tau)$ (degree of Yukawa unification) for solutions with R~1.
- Yukawa-unified solutions are found only for special choices of GUT scale boundary conditions:
  - $A_0^2 = 2m_{10}^2 = 4m_{16}^2$
  - $m_{16}$ ~ 5 - 15 TeV
  - $m_{1/2}$ much less than $m_{16}$ (20-100 GeV)
  - $\tan(\beta)$ ~50
- Then SUSY mass spectrum is given by:
  - First and second generation squarks and sleptons: ~10 TeV
  - Third generation squarks, sleptons, $\mu$ and $m_A$ :~1 - 3 TeV
  - Light gluinos with ~300-600 GeV, charginos with 100-180 GeV
  - The lightest neutralino with 50-90 GeV
  - SUSY events are characterized by gluino pair production followed by 3-body decays to states with high multiplicity of b-jets. In addition, OSSF dileptons with mass 40-80 GeV is expected.

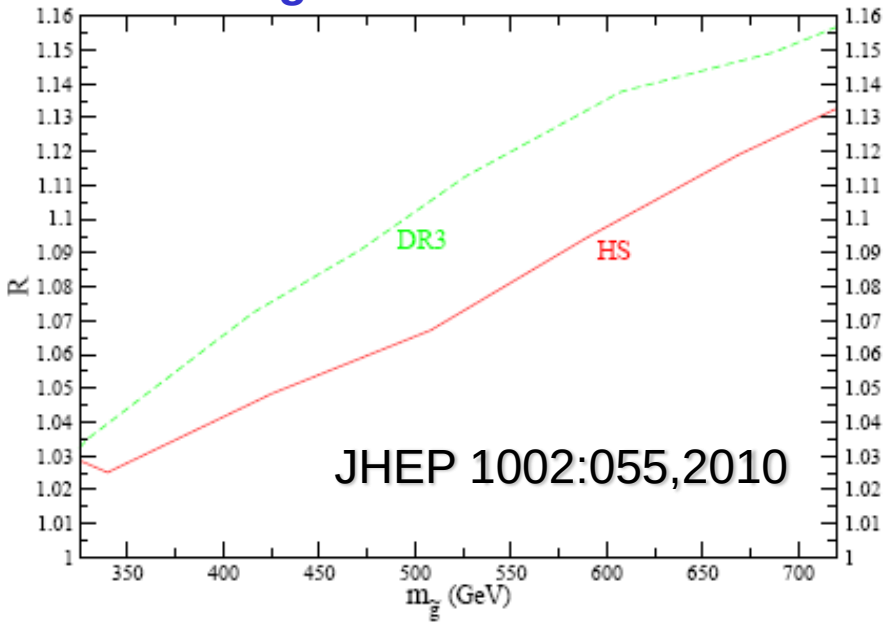
# SO(10) SUSY Monte Carlo Samples – Scan of $m_{1/2}$ (Scan of gluino mass)

| m1/2 (GeV) | Sigma (NLO) (pb) |
|---|---|
| 35 | 42.6 |
| 44 | 31.6 |
| 60 | 16.2 |
| 75 | 9.2 |
| 90 | 5.6 |
| 105 | 3.6 |
| 120 | 2.4 |
| 135 | 1.6 |
| 150 | 1.2 |
| 165 | 0.9 |
| 180 | 0.6 |

| m1/2 (GeV) | Sigma (NLO) (pb) |
|---|---|
| 34 | 37.5 |
| 45 | 21.8 |
| 60 | 11.6 |
| 75 | 6.8 |
| 90 | 4.3 |
| 105 | 2.7 |
| 120 | 1.9 |
| 135 | 1.3 |
| 150 | 0.9 |
| 165 | 0.7 |
| 180 | 0.5 |

Two model lines: HS model
DR3 model

**Degree of Yukawa Unification versus gluino mass**




With $m_{1/2}$=180, getting quite out of good Yukawa unified region, thus model excluded (gluinos above ~600 GeV)