Searches for Supersymmetry at ATLAS

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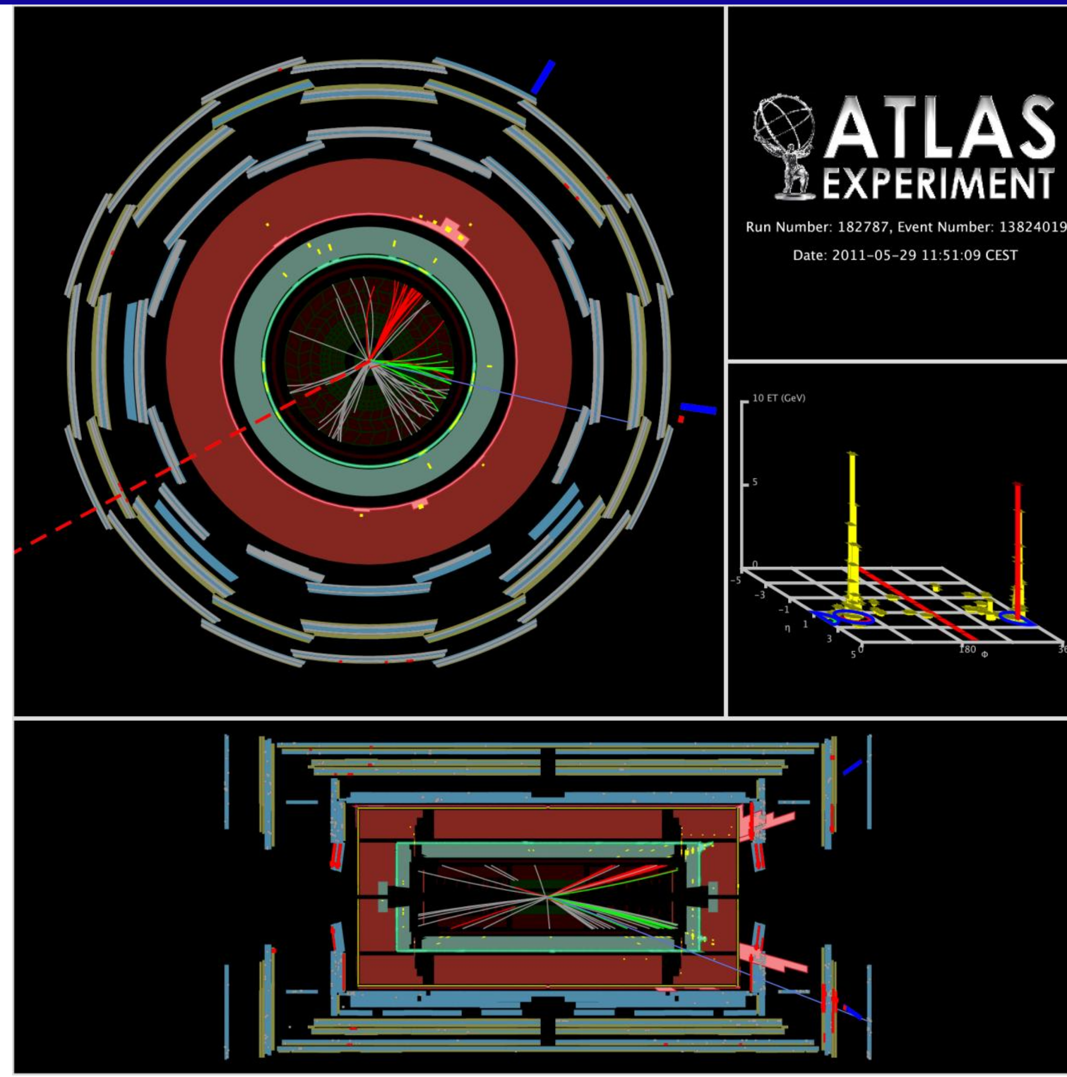
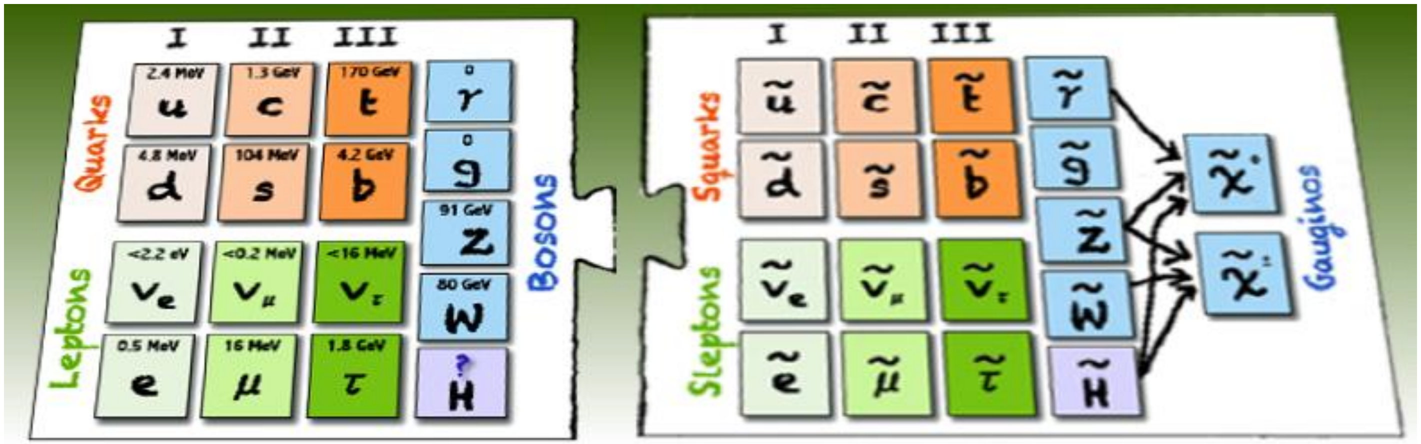
On behalf of the ATLAS Collaboration



- $pp \rightarrow \tilde{b}_1\tilde{b}_1 + X$ **candidate**
- **2 b-tagged jets pT ~ 152 GeV and 96 GeV**
- **E_T^{miss} ~ 205 GeV, $M_{CT}(bb)$ ~ 201 GeV**

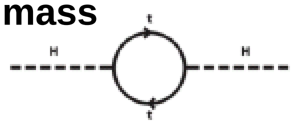
Supersymmetry

- ✓ **<u>New symmetry between fermions and bosons</u>**
  - A superpartner for every SM particle differing by half unit of spin
  - At least 2 Higgs doublets



Physics motivations:

- ✓ TeV scale supersymmetry motivated by gauge hierachy problem
  - Stabilize the Higgs mass



- ✓ Other pros:
  - Good dark matter candidate
  - Gauge unification

no protection against baryon or lepton number violation by default

=> Postulate a new quantum number R:
SM R=+1, SUSY R=-1

For R-parity conserving models:

- ○ SUSY particles produced by pairs
- ○ Lightest susy particle (LSP) is stable
- ⇒ Large impact on phenomenology

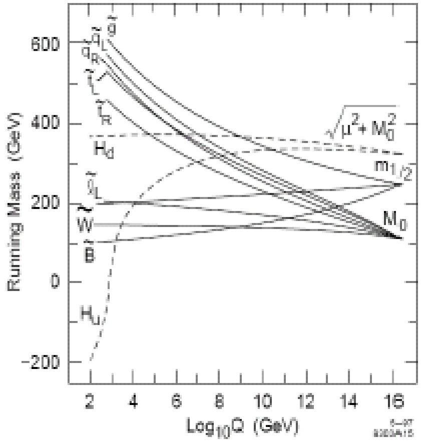
Signals

- ✓ Supersymmetry is a theory => plethora of models
- ✓ Simplest extension of SM the MSSM has 105 new parameters
- ✓ How to test that at LHC ?

1. Top/down approachs:

• Supersymmetry is broken, different models: Gravity mediated (SUGRA), Gauge mediated (GSMB), …

• GUT scale unification => few free parameters



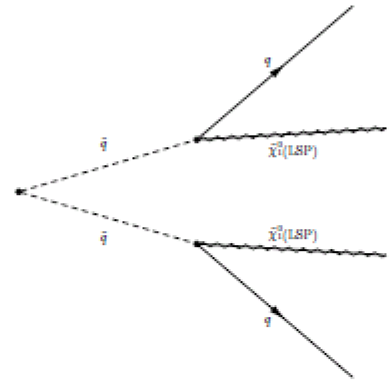
• Benchmark model: **CMSSM / mSUGRA**

- m_0 common scalar mass (GUT)
- $m_{1/2}$ common gaugino mass (GUT)
- $\tan\beta$ ratio of Higgs vacuum expectation values
- A_0 common trilinear coupling
- Sign(μ) Higgs mass term

2. Bottum/up approachs:

a. Pheno. models:
- ✓ Assume masses and hierarchy
- ✓ Scan remaining parameters

b. Simplified models:
- ✓ Specific decay chain



- ✓ Kinematic and rate determined by very few mass parameters

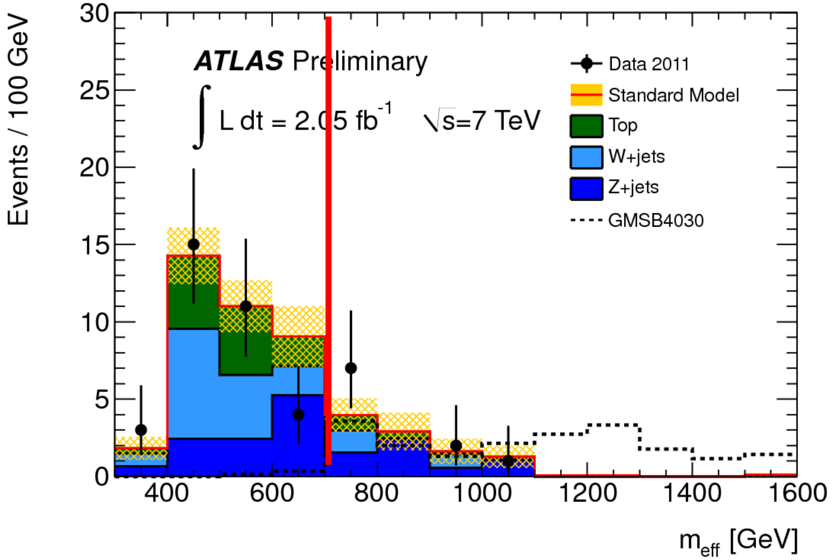
A typical analysis

✓ **Simple « cut & count » analysis**

- **Many jets + large E_t^{miss} + eventually leptons(inc. taus)/photons/bjets**
- **Cut sufficiently hard to reduce largely unknown background processes (fake MET, fake-leptons from QCD)**
- **Apply discriminating cuts to enhance signal/background ratio**

$$m_{eff} = \sum_{jets} p_T + \sum_{lept.} p_T + E_T^{miss}$$

2-τ+E_T^{miss} analysis

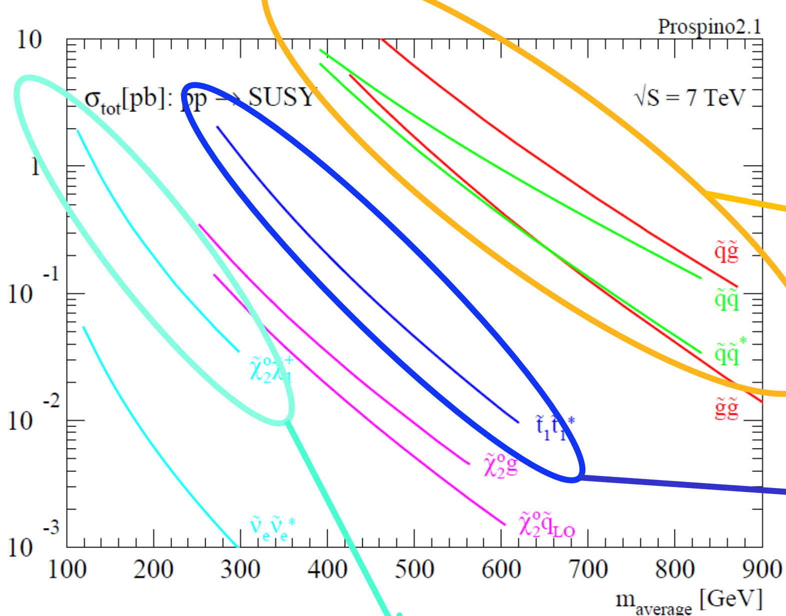


✓ **Remaining backgrounds estimated via**

- **Fully data-driven methods for difficult bkgs (QCD, fake-leptons)**
- **Semi-data-driven methods for main processes**

$$N_{SR}^{est.} = N_{SR}^{MC}/N_{CR}^{MC} \times (N_{CR}^{obs} - N_{CR}^{bkg})$$

ATLAS SUSY Searches



1. Strong production channels:

$$pp \rightarrow \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} + X$$

- **Copious production at hadron colliders**
- **Etmiss based generic search channels**
- **Plus more exotic channels**
  - **Long-Lived (LL) particles**
  - **Resonances**

2. Third generation sparticles searches:

- **Expected from naturalness to be O(< TeV)**
- **Expected lighter than other squarks due to mixing**
- **Can search for more specific final states**

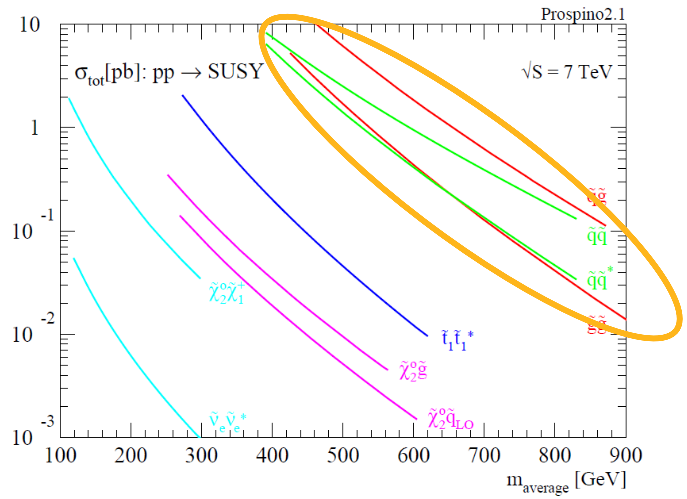
3. Leptons/photons searches:

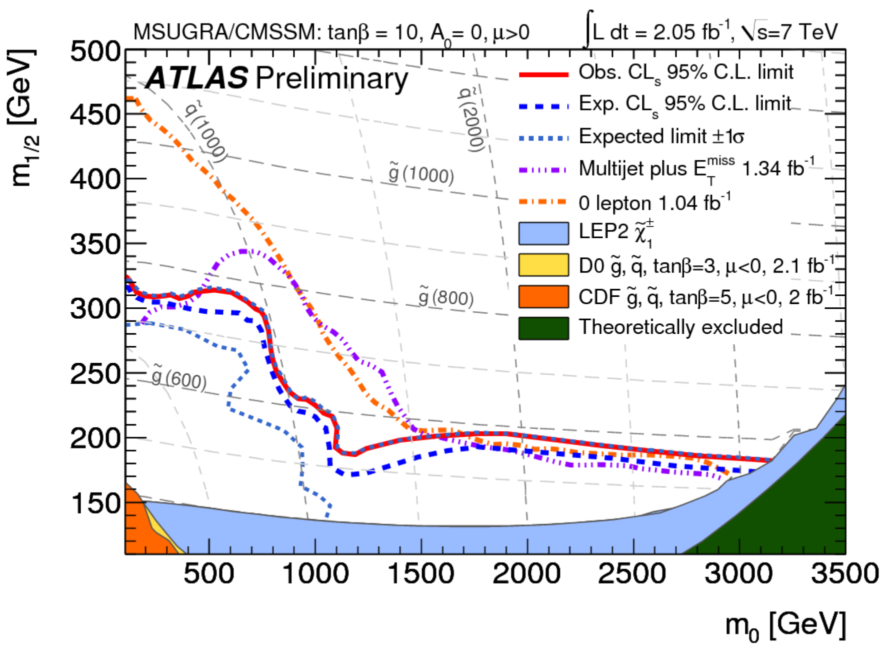
$$pp \rightarrow \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\pm}, \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{0}, \tilde{\chi}_i^{0}\tilde{\chi}_j^{0} + X$$

Relevant when:

- **colored spartners are too heavy => direct gaugino production**
- **RPV decays**
- **Gauge-Mediated models**

Strong production – R-parity conserving models





- **SUSY particles mainly produced via strong interaction (gluino, squarks) at hadron colliders**

If R-parity is conserved:

- **sparticles produced by pair**
- **decay to invisible LSP**

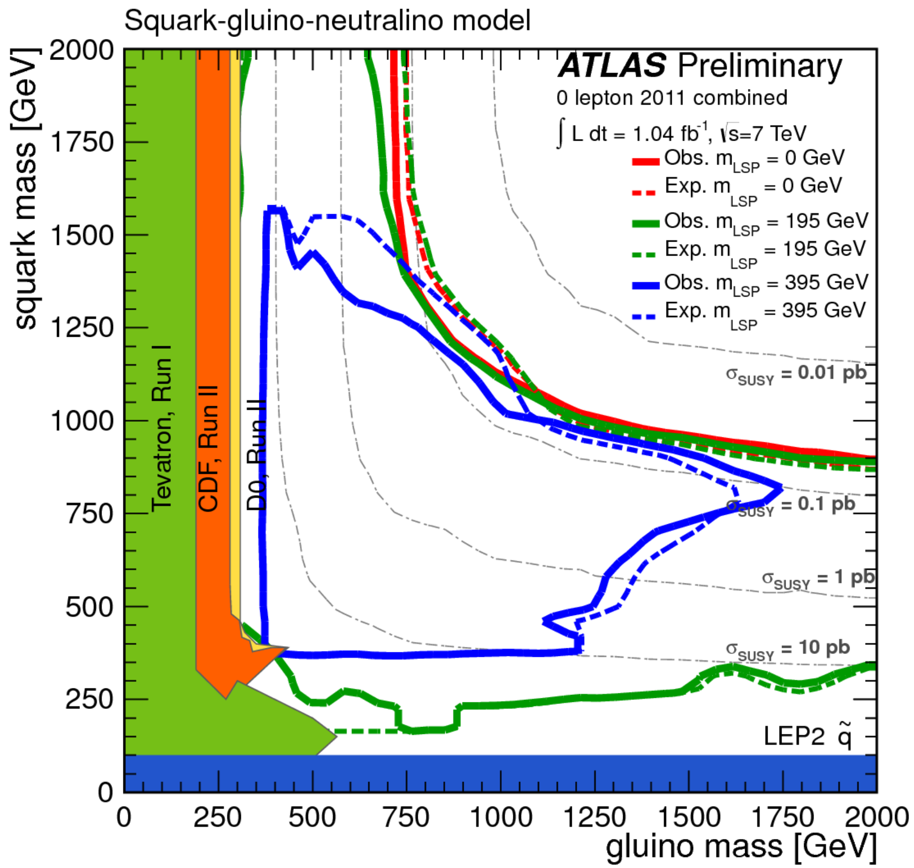
⇒ Search for jets + E_t^{miss} + 0,1,2-leptons

Benchmark, interpretation in CMSSM:

- **Exclude m ~ 1075 GeV for m(~q)=m(~g)**
- **3 very different analysis confirm exclusion limit at high m_0**
- **Update with 5 fb^{-1} foreseen in coming weeks**

Strong production, bottom-up interpretations

Pheno MSSM model:
- **Only gluino, squark, LSP**
- **LSP is light**

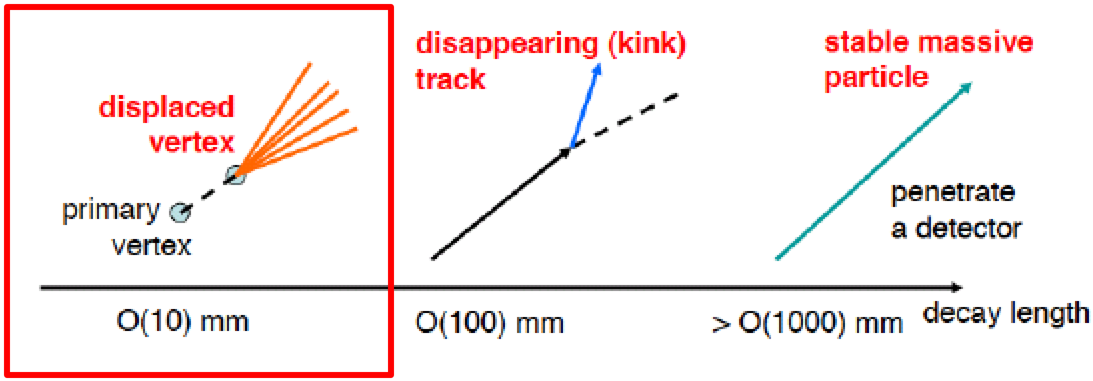


✓ **Limits independent of LSP mass for m(LSP) up to ~ 200 GeV**

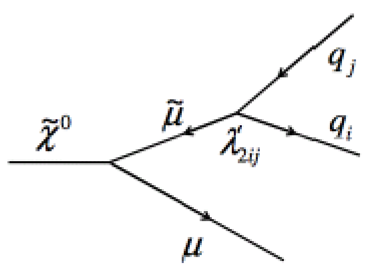
- **See Robin's talk for further results !**
- **Small mass splittings (compressed spectra) will require specific channels**
- **Results (+ acceptance & efficiency) available in HEPDATA format**

…even more exotic channels

… still strong production, but with long-lived supersymmetric particles (RPV, GMSB, AMSB models)

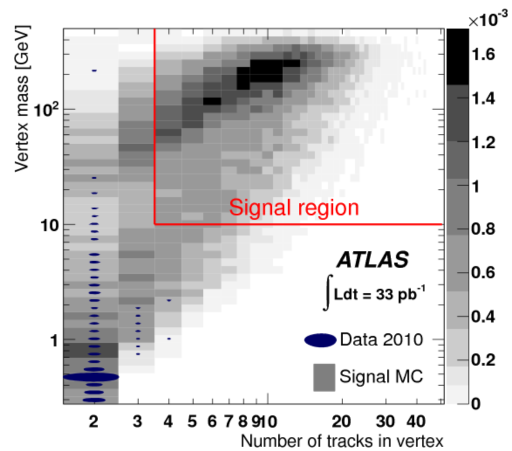


RPV decays of LSP:

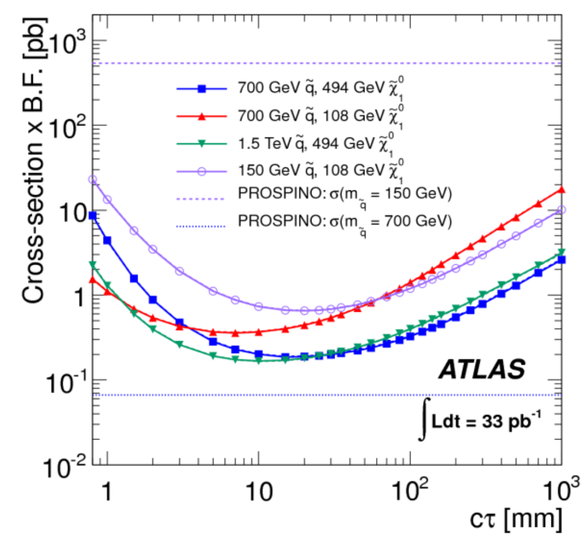


Search for displaced vertex:

- **many tracks**
- **large vertex mass**



Limits depend on lifetime:



…even more exotic channels

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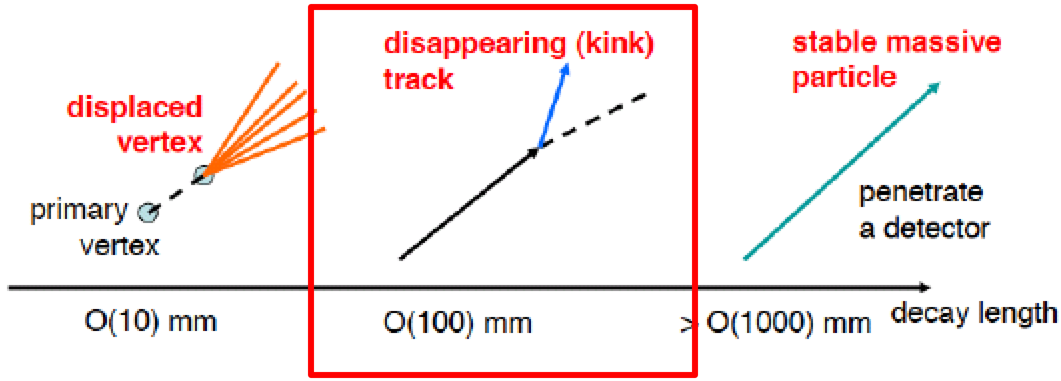
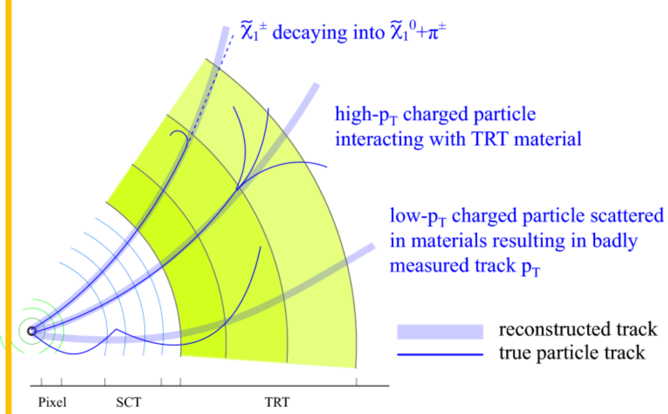
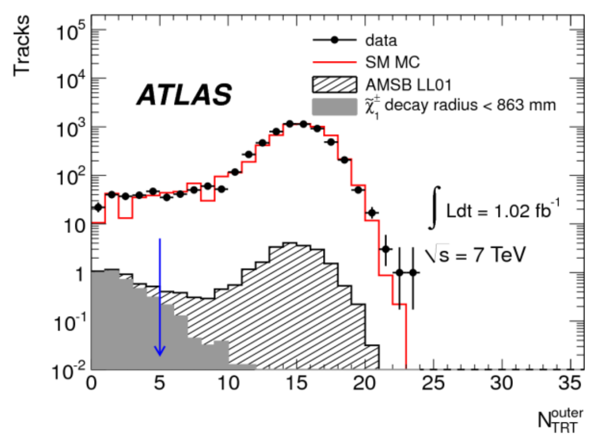


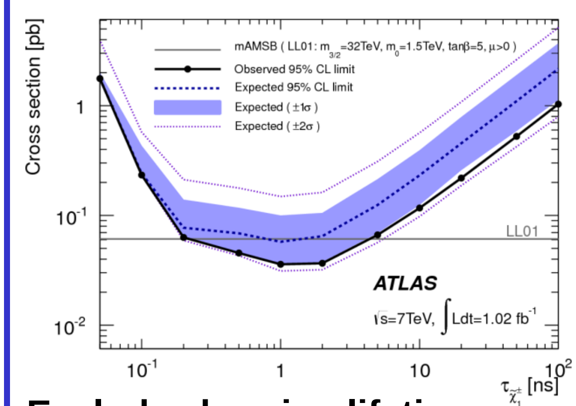
AMSB model: neutralino and chargino are nearly mass degenerate => LL track



Search for disappearing track:

- **small number of TRT hits**



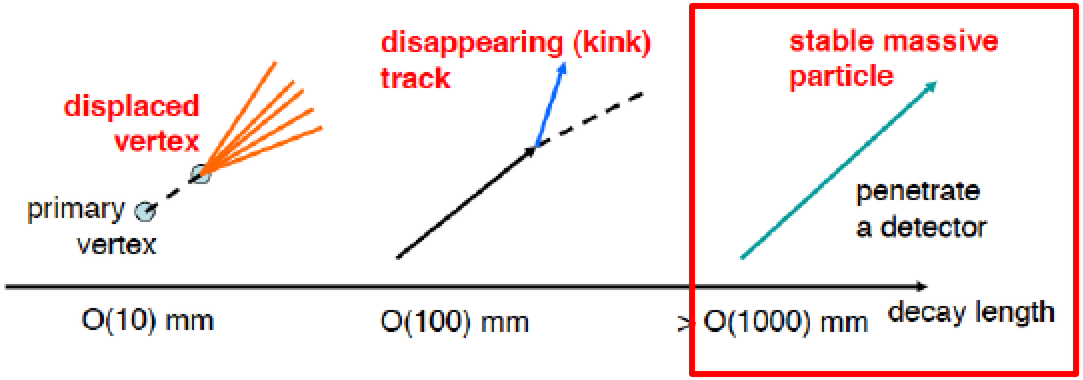


Exclude chargino lifetime between 0.5 and 2 ns for m(chargino) = 90.2 GeV

ATLAS specific study thanks to the Transition Radiation Tracker (TRT)

…even more exotic channels

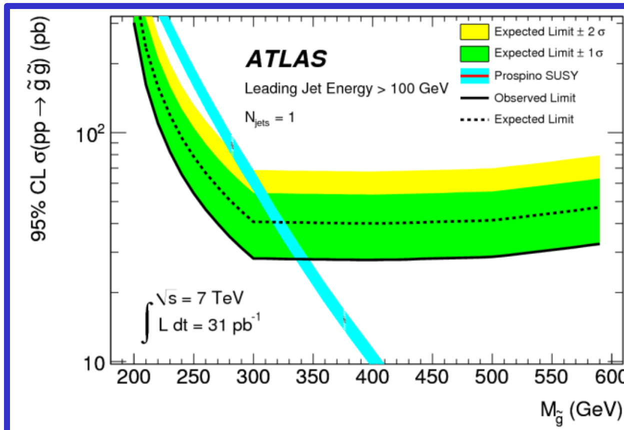
… still strong production, but with long-lived supersymmetric particles (RPV, GMSB, AMSB models)



✓Long-lived sleptons or R-hadrons (gluino or squarks binding with other quarks)

✓ Depending on nature/interaction/lifetime could produce:

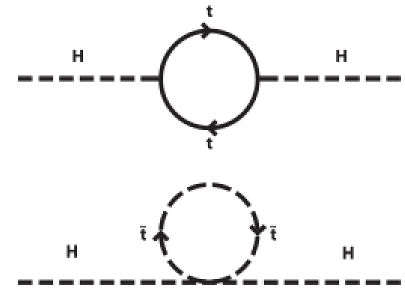
- large ionization loss in trackers
- long time-of-flight in calorimeters
- heavy-like muons (staus) seen in muon spectrometers
- large calorimeter deposit in empty bunch crossings

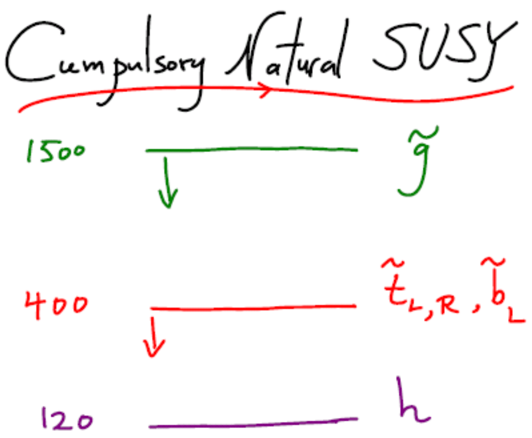


Exclude R-hadron m < 340 GeV if $10^{-5} < \tau < 10^{3}$ s

Third generation search

✓ **Main motivation for TeV-scale SUSY is solving hierarchy problem**
✓ **If SUSY solves the hierarchy problem <u>naturally</u>, then 3rd gen. squarks must be light**





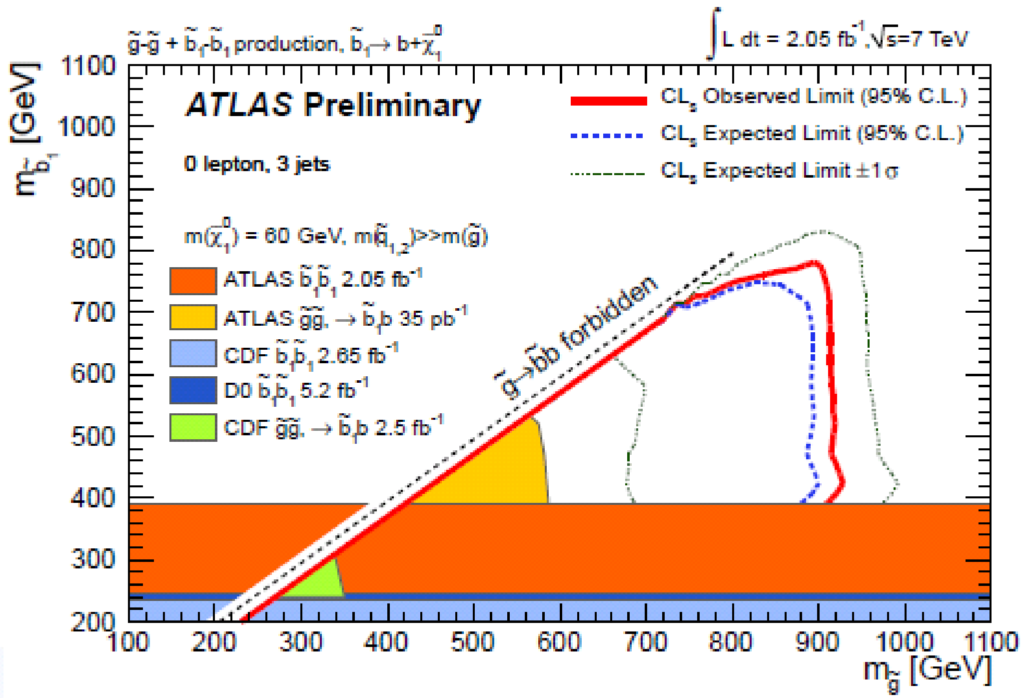
ARKANI-HAMED, Nima Oct 31st 2011
Talk link

<u>Possible search strategies:</u>
✓ **If gluino is light enough => dominant process**
- ○ **gluino pair production**
- ○ $\tilde{g} \rightarrow b\tilde{b}_1,\ \tilde{g} \rightarrow t\tilde{t}_1$
- ○ **Search for b-jets + MET + jets**

✓ **If not and only 3rd gen. squarks are light**
- ○ **sbottom pair production => 2 b-jets + MET**
- ○ **stop pair production => several decay chains depending on mass hierarchy**

Gluino mediated sbottom production

- ✓ **Signature:** **0-lepton + several b-jets + E_t^{miss} => make use of flavor tagging**
- ✓ **Interpretations:** **pheno. MSSM model**
  - **Only gluino, sbottom, LSP**
  - **Mass spectrum:** $m(\tilde{g}) > m(\tilde{b}_1) > m(\tilde{\chi}_1^0)$

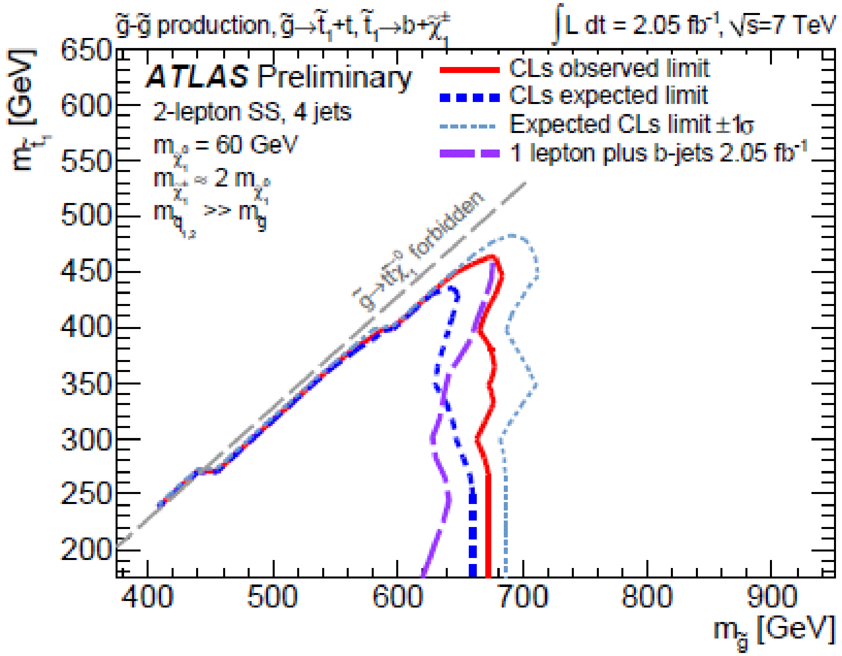


- ✓ **Exclude m(gluino)<900 GeV for m(sbottom) up to ~ 800 GeV**

Gluino mediated stop production

- ✓ **Signatures:**
  - a. **1-lepton + several b-jets + E_t^{miss}**
  - b. **2 same sign leptons + several jets + E_t^{miss}**
- ✓ **Interpretations: <u>Pheno MSSM model:</u>**
  - ○ **Only gluino, stop, chargino, LSP**
  - ○ **Mass spectrum:** $m(\tilde{g}) > m(\tilde{t}_1) > m(\tilde{\chi}_1^\pm) = 2 \cdot m(\tilde{\chi}_1^0)$

$$Br(\tilde{t}_1 \to b\tilde{\chi}_1^\pm) = 1$$

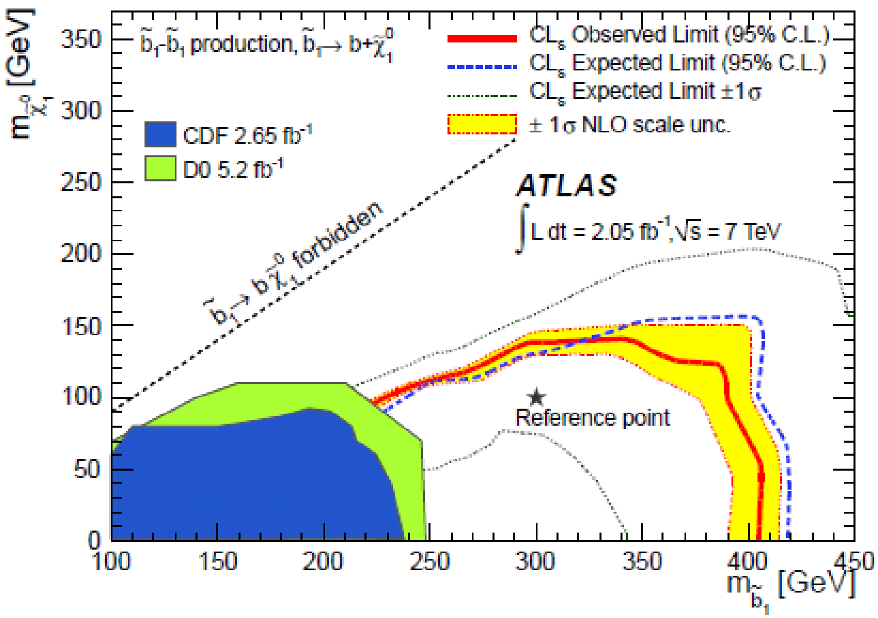


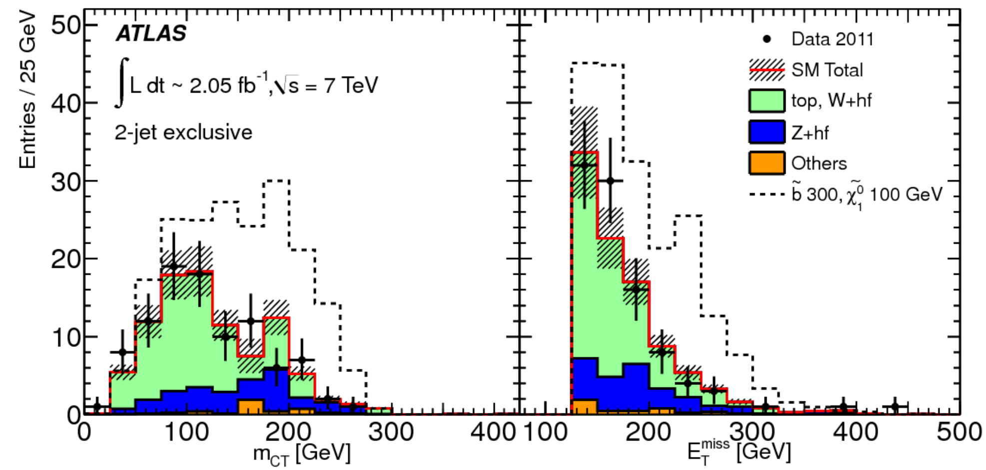
✓ **Exclude m(gluino)<650 GeV for m(stop) up to ~ 450 GeV**

Direct sbottom pair production

✓ **Signature: exactly 2 b-jets + E_t^{miss} => make use of flavor tagging**

✓ **Interpretations: pheno. model with** $Br(\tilde{b}_1 \to b\tilde{\chi}_1^0) = 1$





$$m_{CT}^2(v_1, v_2) = [E_T(v_1) + E_T(v_2)]^2 - [\mathbf{p}_T(v_1) - \mathbf{p}_T(v_2)]^2$$

$$m_{CT} \propto (m_{\tilde{b}_1} - m_{\tilde{\chi}_1^0})^2 / m_{\tilde{b}_1}$$

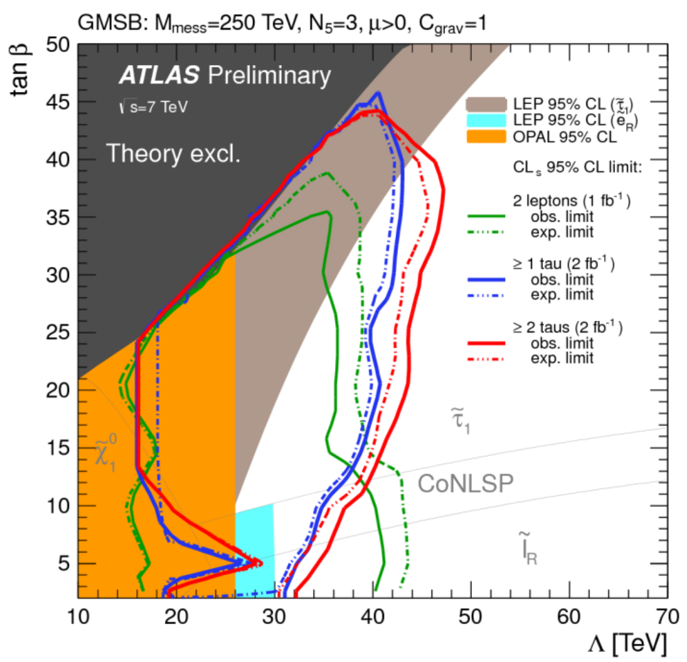
✓ **Excluding sbottom mass < 380 GeV for neutralino masses up to ~ 100 GeV**

✓ **What about stop pair production ?**
- **Effort ongoing but harder because numerous decay chains**
- **Cross-section is small (scalar), difficult to distinguish from top pairs**

SUSY signatures with tau leptons

✓ For each SM fermion, two scalar sfermion $(\tilde{f}_L, \tilde{f}_R)$
✓ Gauge eigenstates mix to form mass eigenstates $m(\tilde{f}_1) < m(\tilde{f}_2)$
✓ Mixing ∝ yukawa coupling => 3rd gen. sfermions are often lightest

<u>Consequence</u>: $\tilde{\tau}_1$ is lightest slepton, very often NLSP in GMSB models



Tau decays
- **hadrons (65%)**
- **leptons (35%)**

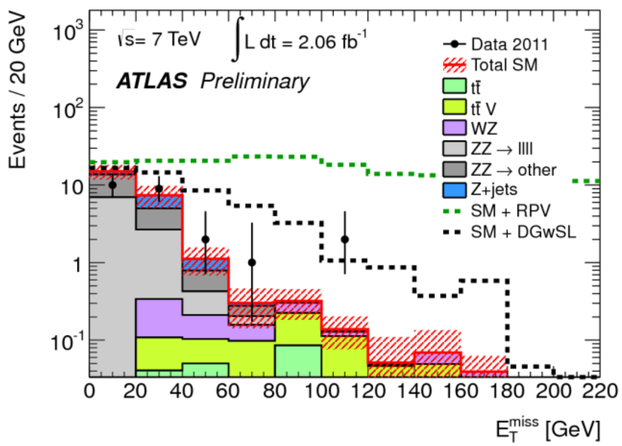
⇒ <u>signatures:</u>
✓ **2 opposite sign electron(s)/muon(s)**
✓ **1 hadronic tau + jets + E_t^{miss}**
✓ **2 hadronic taus + jets + E_t^{miss}**
1 hadronic tau + 1 muon + jets + E_t^{miss} (on-going)

Independently of tan(β), Λ < 31 TeV is excluded

Lepton(s)/photon(s) based signatures

<u>4-leptons search:</u>

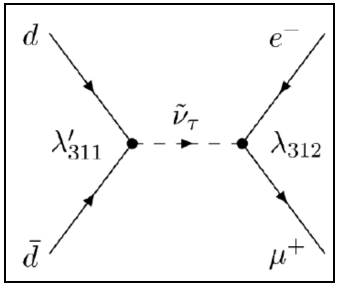
- **RPV decays**
- **Direct gaugino production**

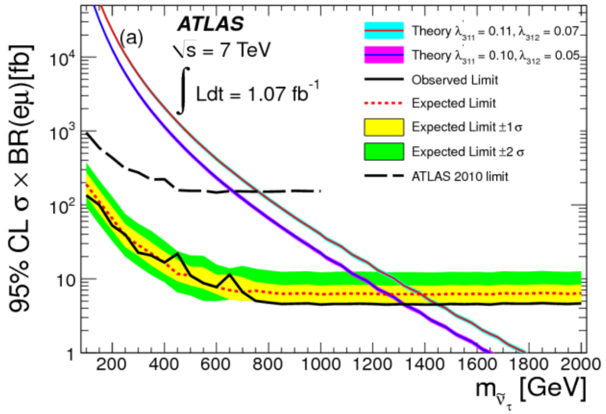


✓ **No specific excess found**

<u>eμ resonance:</u>

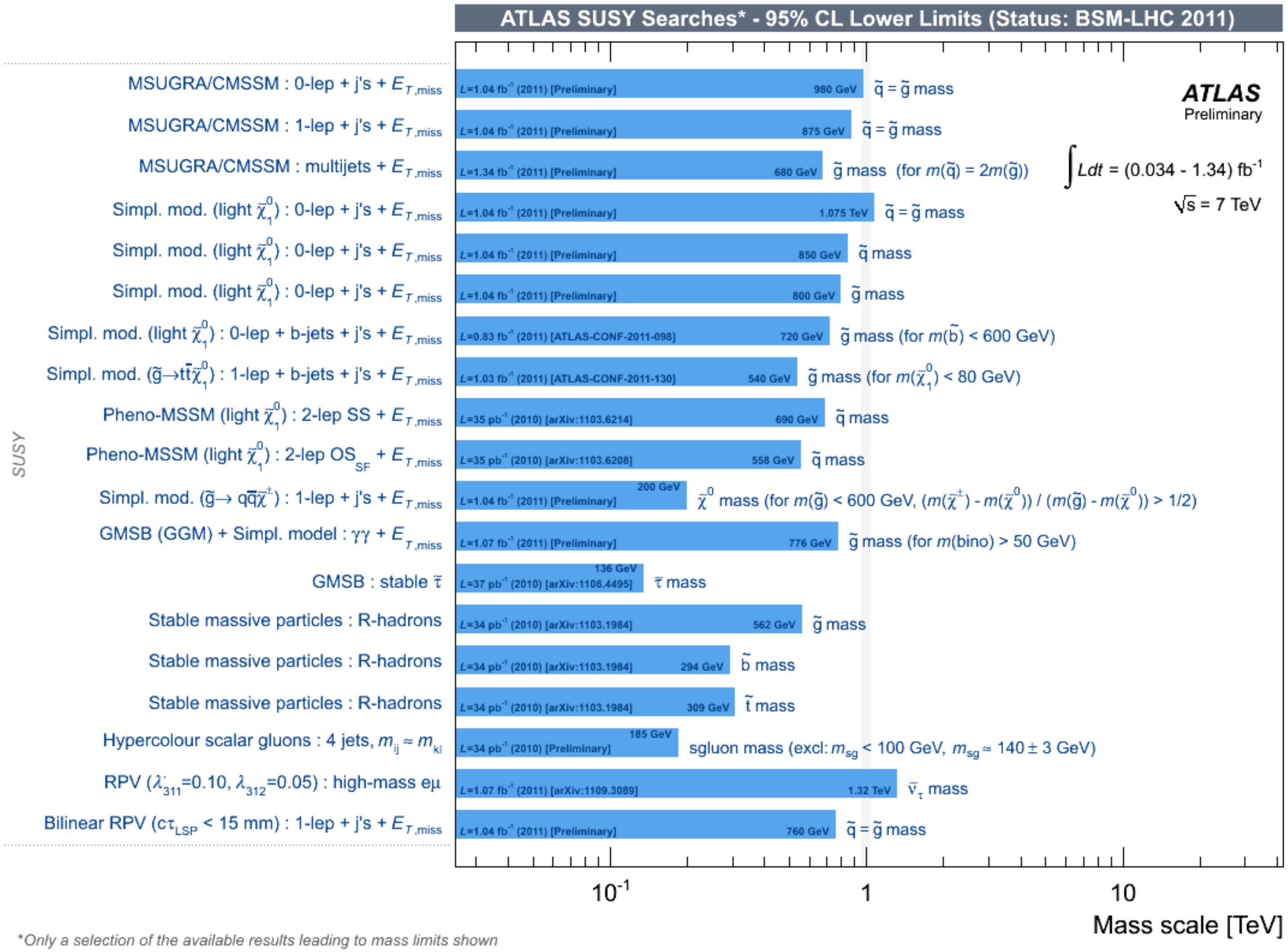
- **RPV decay of sneutrino**





+ Large ongoing effort to extend ATLAS searches to direct gaugino production

ATLAS SUSY searches limits



We are approaching limits on TeV-scale new physics

Summary

- **Generic SUSY searches:**
  - **Simplest SUSY models have been excluded up to TeV scale**
  - **But there is still a long way till light SUSY is excluded:**
    - **Compressed spectra**
    - **Long decay chains**
    - **Long-lived particles**
    - **R-parity violation models**

- **Naturalness problem:**
  - **Extensive search of third generation sparticles started and is ongoing**
  - **Many new results expected in coming weeks**

- **Keep informed / read more (~ 20 papers in 1 year) by looking at:**

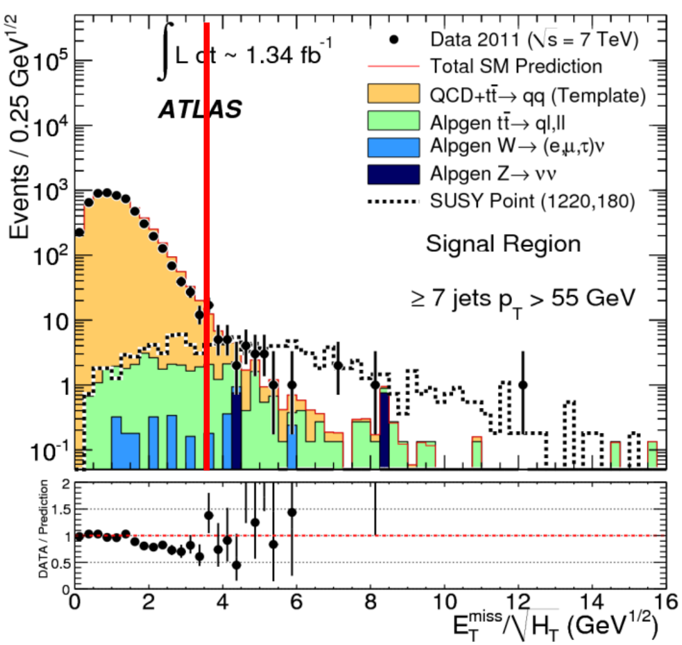
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Backup

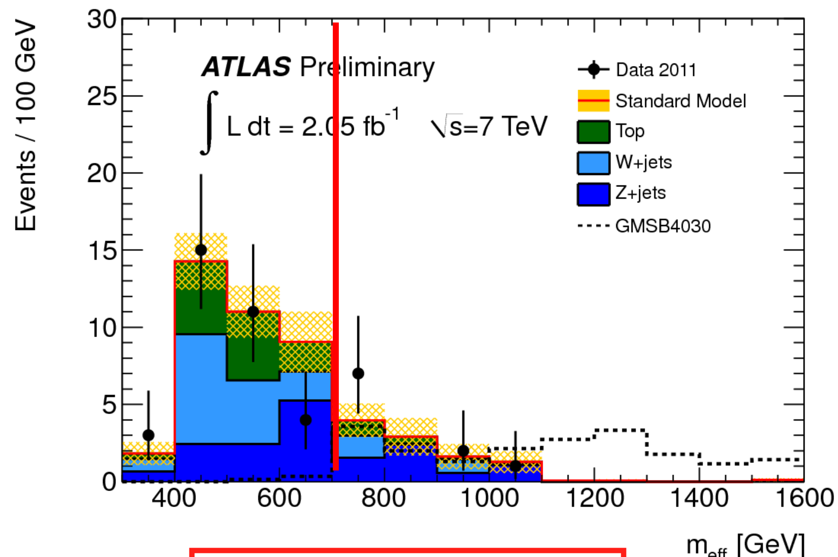
A typical analysis

- ✓ **simple « cut & count » analysis**
  - ○ **Many jets + large E_t^{miss} + eventually leptons(inc. taus)/photons/bjets**
- ✓ **Cut sufficiently hard to reduce largely unknown background processes (fake MET, fake-leptons from QCD)**
- ✓ **Apply discriminating cuts to enhance signal/background ratio**

Multijets analysis



2-τ+E_T^{miss} analysis



$$m_{eff} = \sum_{jets} p_T + \sum_{lept.} p_T + E_T^{miss}$$

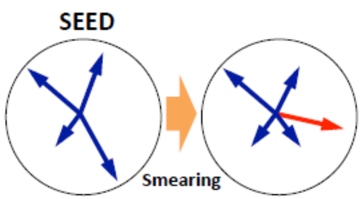
A typical analysis

- ✓ simple « cut & count » analysis
- ✓ Cut sufficiently hard to reduce largely unknown background processes (fake MET, fake-leptons from QCD)
- ✓ Apply discriminating cuts to enhance signal/background ratio

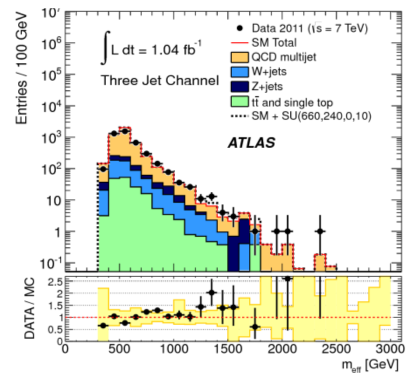
✓ Remaining backgrounds are estimated via

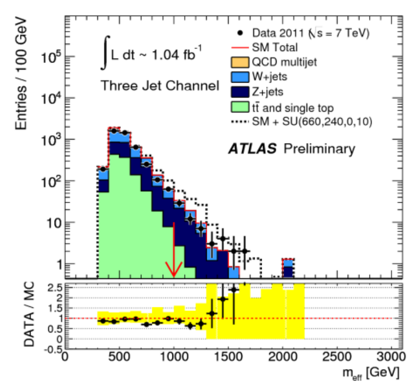
- ✓ **Fully data-driven methods for difficult but small processes**

1. Determine the jet response function R from dijet balance and 3-jets mercedes events
2. Take a control sample of multijets events with small MET.
3. Smear each jet by its response R



4. Normalize the shape obtained in a QCD enhanced region with low $\Delta\phi(\text{jet}, E_T^{miss}) < 0.4$
5. Propagate to signal region





A typical analysis

- ✓ simple « cut & count » analysis
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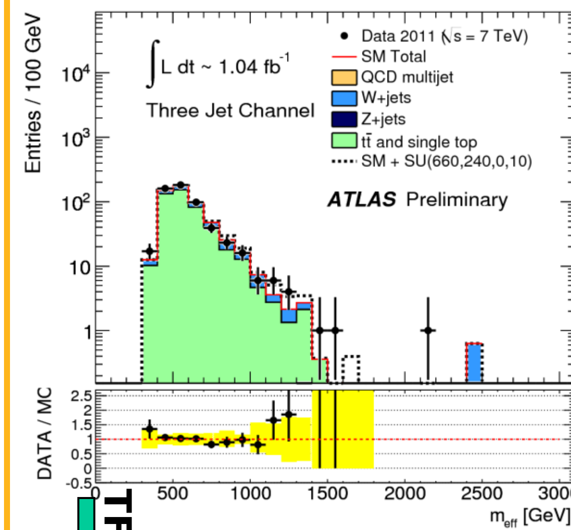
✓ Remaining backgrounds are estimated via

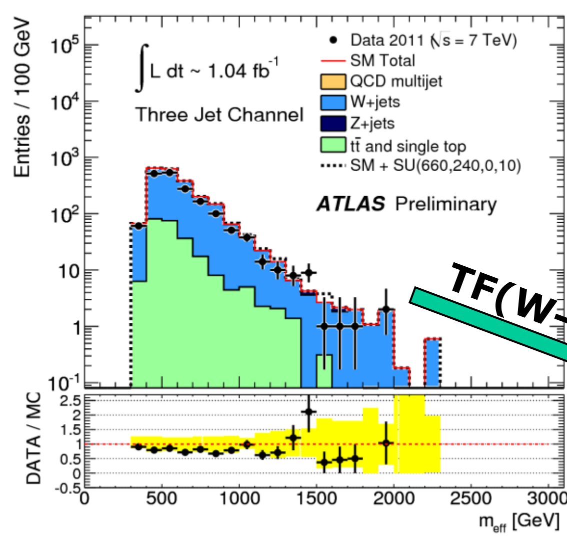
- ✓ Fully data-driven methods for difficult but small bkgs
- ✓ **Semi-data-driven methods for main processes**

$$N_{SR}^{est.} = N_{SR}^{MC}/N_{SR}^{MC} \times (N_{CR}^{obs}-N_{CR}^{bkg})$$

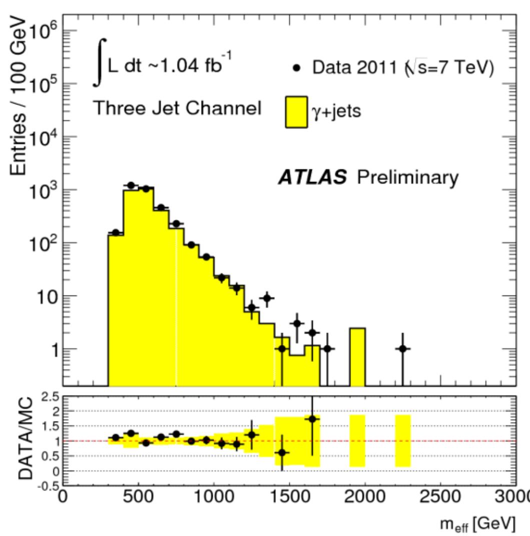
Top CR: 1lep+bjet+MET+3jets



W CR: 1lep+nobjet+MET+3jets



Z CR: γ+3jets

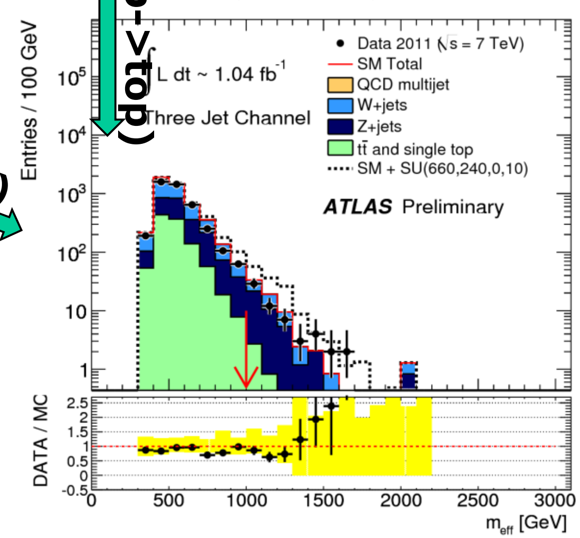


TF(top->top)

TF(W->W)

TF(γ->Zνν)

Signal Region



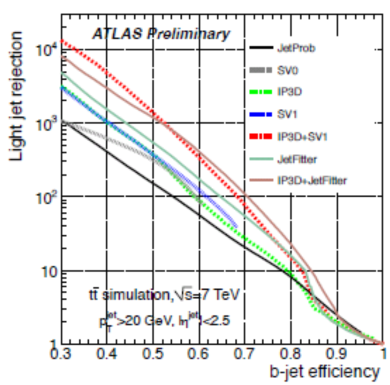
Reconstructing b-jets, tau hadrons

B-jets are identified via IP3D+JetFitter tagger based on:

- **IP3D: transverse and longitudinal impact parameters of the tracks in the jets**
- **JetFitter: vertices of b- and c-Hadrons decays are inside the jet**

Working point selected with:

- **60% efficiency for b-jets produced in top pairs process**
- **Mis-tag rate < 1%**



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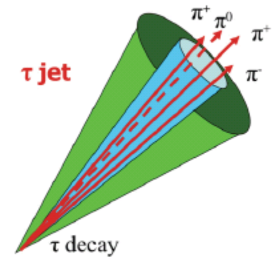
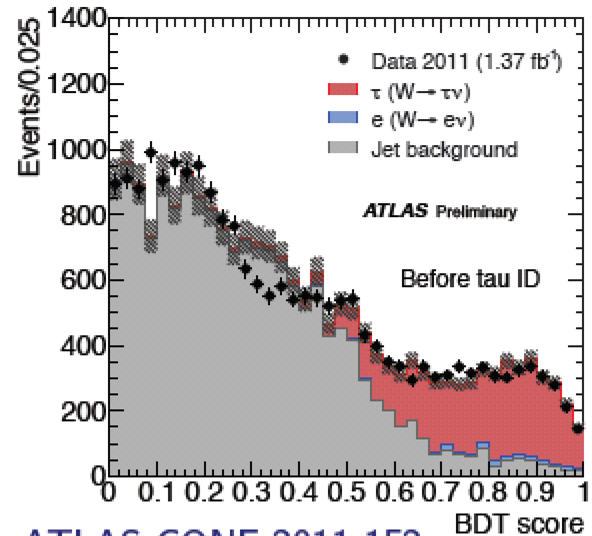
Tau hadrons, contrary to hadronic jets:

- **Are well collimated**
- **Have large electromagnetic fraction**

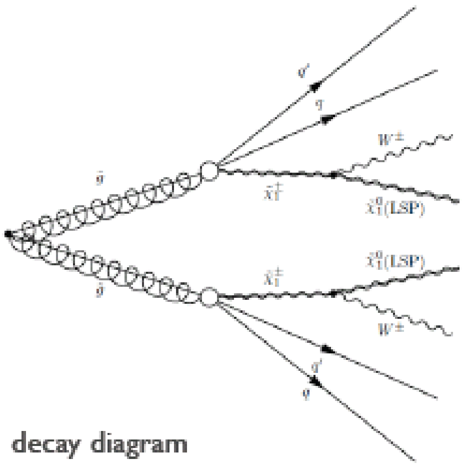




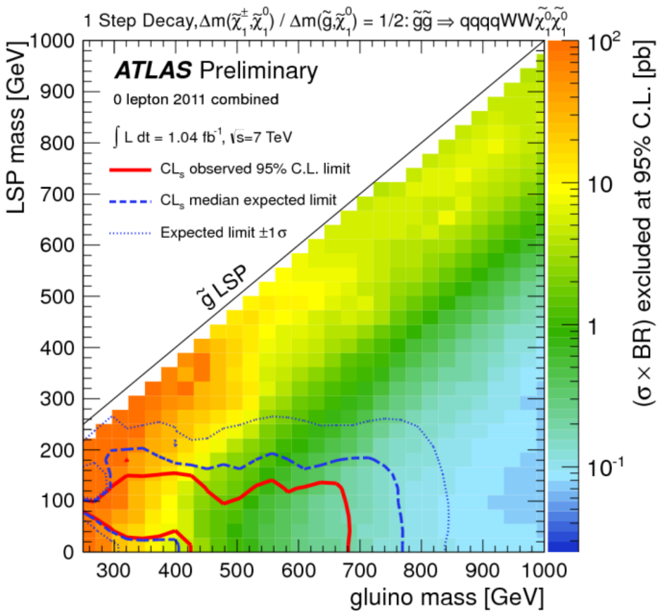
ATLAS-CONF-2011-152

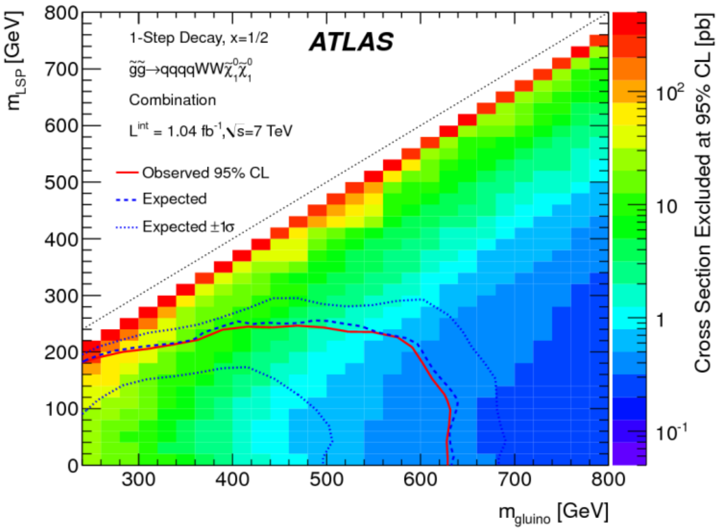
Strong production, simplified models

- Only gluino, LSP are accessible
- 1 step decay involving a W => 0- or 1-lepton + jets +MET signatures



decay diagram





✓ **Exclude m(gluino)<600 GeV for m(LSP) up to ~ 200 GeV**

- **Highlight complementarity of channels without/with leptons**
- **Small mass splittings (compressed spectra) will require specific channels**

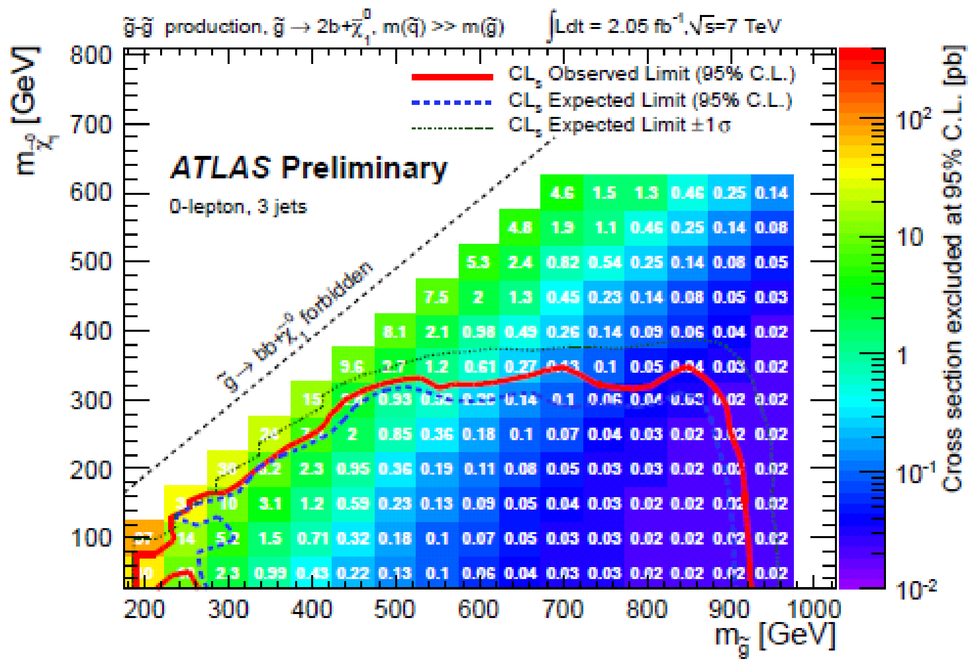
Gluino mediated sbottom production (simplified model)

✓ **Signature: 0-lepton + several b-jets + E_t^{miss} => make use of flavor tagging**

✓ **Interpretations:**

<u>Simplified model:</u>

- **Only gluino, sbottom, LSP**
- **Mass spectrum:** $m(\tilde{b}_1) > m(\tilde{g}) > m(\tilde{\chi}_1^0)$



✓ **Exclude m(gluino)<900 GeV for m(LSP) up to ~ 300 GeV**

Gluino mediated stop production

✓ **Signatures:**

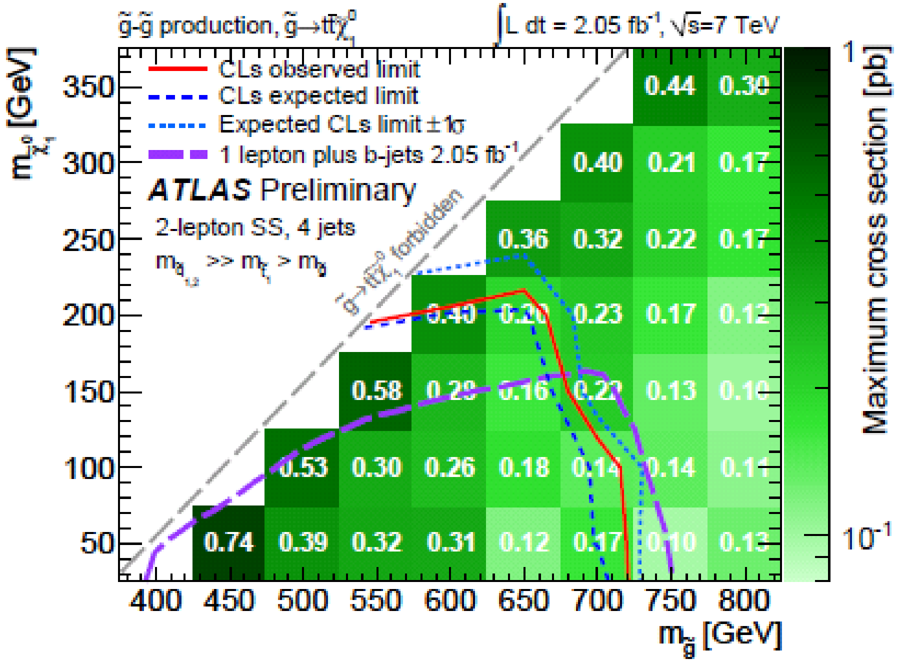
a. **1-lepton + several b-jets + E_t^{miss}**

b. **2 same sign leptons + several jets + E_t^{miss}**

✓ **Interpretations:**

Simplified model:

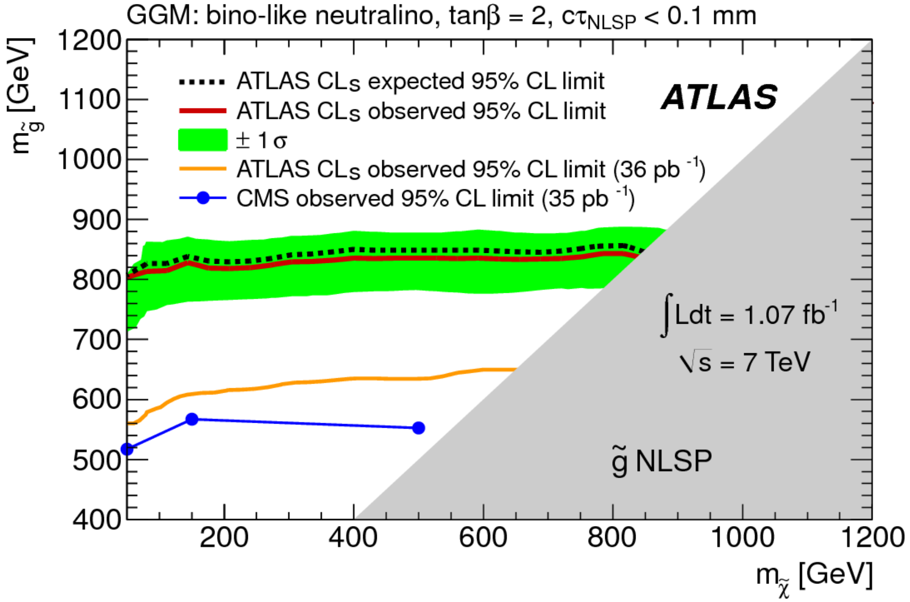
- **Only gluino, stop, LSP**
- **Mass spectrum:** $m(\tilde{t}_1) > m(\tilde{g}) > m(\tilde{\chi}_1^0) \quad Br(\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0) = 1$



✓ **Exclude m(gluino)<650 GeV for m(LSP) up to ~ 215 GeV**

Gauge mediation:

- Bino NLSP: $\chi_1^0 \rightarrow \gamma G$
- Search for $2\gamma + E_T^{miss}$



✓ **Exclude gluino masses ~ 800 GeV independently of neutralino mass**