ATLAS Overview of MET Signatures

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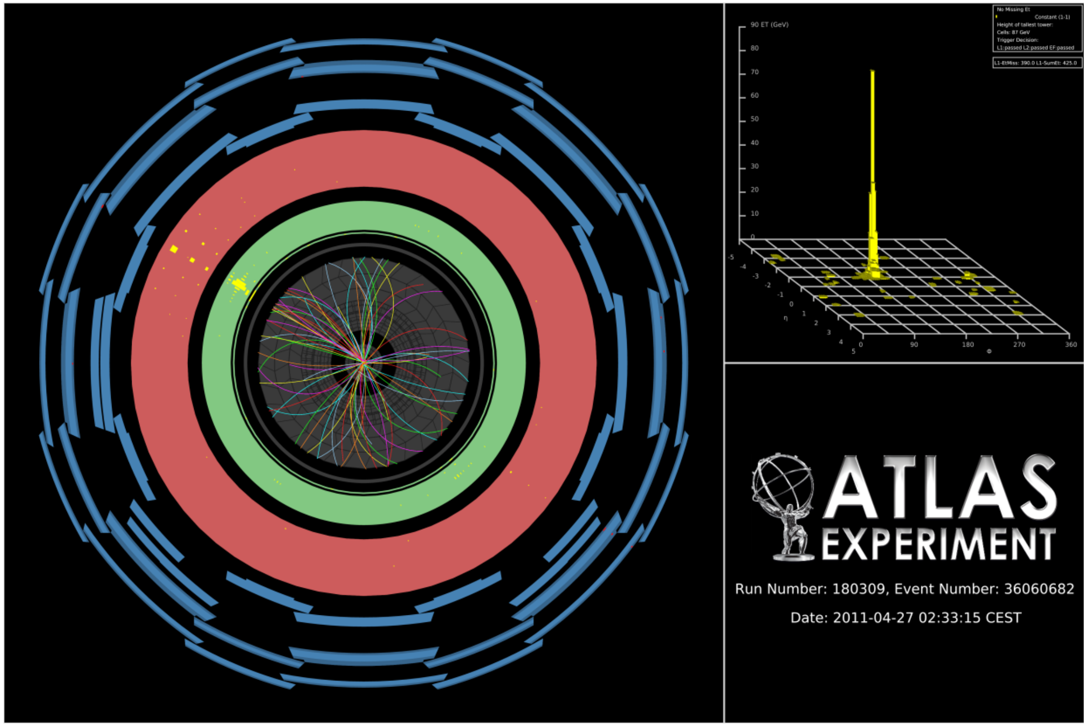
On behalf of ATLAS Collaboration

Outline

- **Analysis and signatures**
- **Results and interpretations**
- **Short term plans**



Monojet event, 1jet p_T=602 GeV, MET=523 GeV, no further jet with p_T> 30 GeV

Analysis and Signatures

Or

How we design ATLAS Etmiss based analysis

Designing an analysis ?

Till now, ATLAS early searches were based on simple « cut & count » analysis

1. **Find best trigger**
2. **Cut sufficiently hard to reduce largely unknown background processes (fake MET, fake-leptons from QCD)**
3. **Apply discriminating cuts to enhance signal/background ratio**
4. **Predict remaining backgrounds with fully- or semi- data-driven techniques**
5. **Combine all information in a single likelihood, validate your model and perform tests**

Triggers

1st principle: we can analyze only data on tape !

→ **Trigger is often driving the main analysis cuts**

What are the main trigger objects:

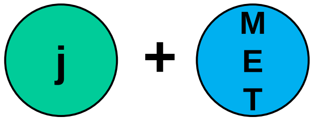
Object	Unprescaled thres.
j	$p_T^{jet} > 350$ GeV
MET	$p_T^{miss} > 150$ GeV
e	$p_T > 25$ GeV
μ	$p_T > 20$ GeV
γ	$p_T > 85$ GeV

But also:

b τ

These thresholds can be lowered by combining objects

Main trigger chains

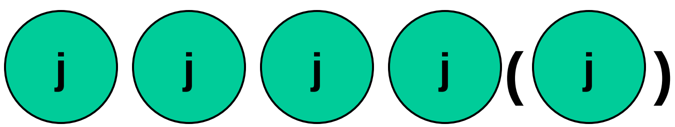


$p_T^{jet} > 130$ GeV + $p_T^{miss} > 130$ GeV

- 0-lepton + MET + 2,3,4 jets
- 0-lepton + MET+ b-jet + 3 jets
- 0-lepton + MET + 2 b-jets
- monojet + MET
- tau + X + MET

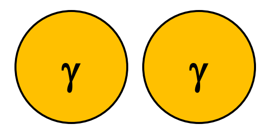
- 1-lepton + MET + 3,4 jets
- 1-lepton + MET + b-jet + 4 jets
- ttbar->lvqq + MET
- 2-leptons + MET
- 3-leptons + MET

Multileptons triggers in future



4jets > 80 GeV OR 5 jets > 55 GeV

- 0-lepton + multijets + MET/$\sqrt{H_T}$



2-photons $p_T > 25$ GeV

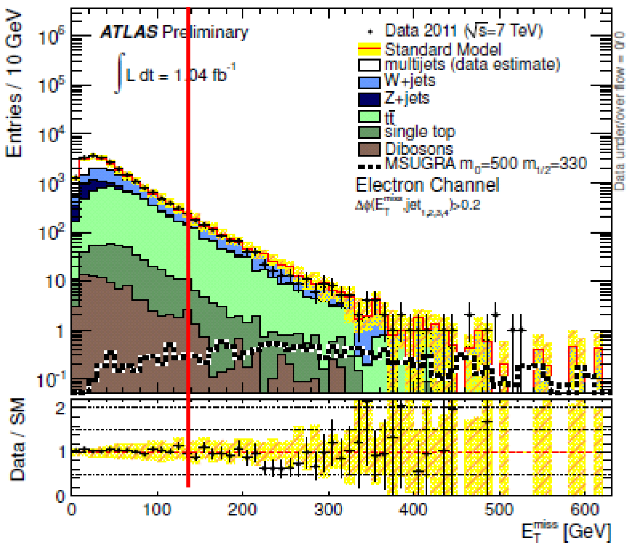
- 2-photons + MET

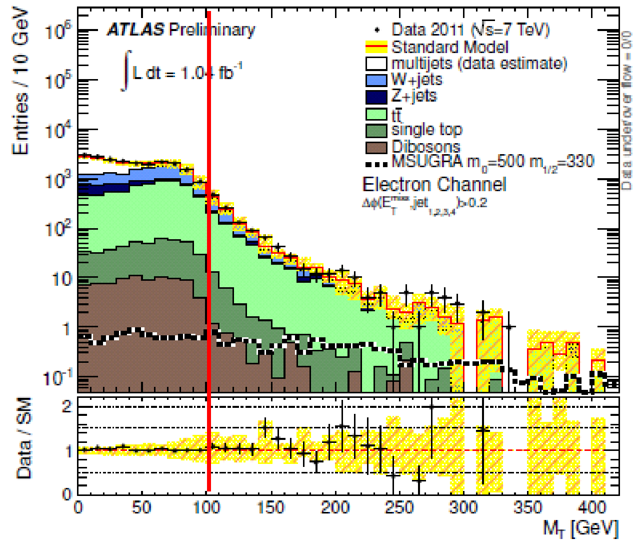
✓All these triggers will get harsher with increasing luminosity

✓ Trigger is a limitation to what we can do: soft MET + soft jets…

Example: 1-lepton + MET + jets channel

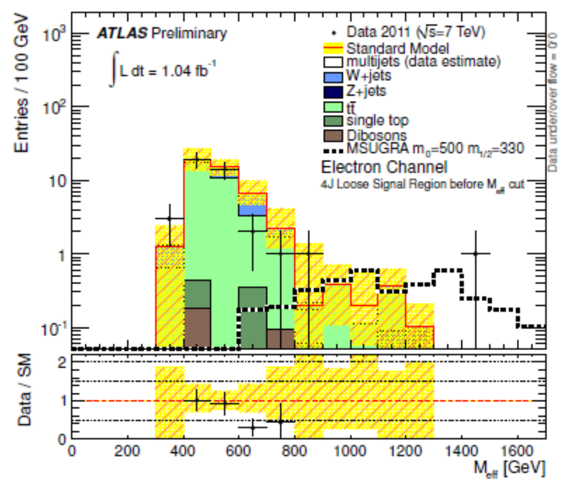
1- Reduce semileptonic ttbar and W backgrounds





2- Enhance signal by cutting on m_{eff}

$$m_{\text{eff}} = p_T^{\ell} + \sum_{i=1}^{3(4)} p_T^{\text{jet}_i} + E_T^{\text{miss}}$$



Dealing with remaining backgrounds

Data vs MC methods

Fully data-driven

Pros:

- Do not rely on potential failures in simulation
- Suited for large σ processes

Cons:

- Rely strongly on simplifying assumptions

Targets: fake-MET, fake-leptons backgrounds

Semi data-driven

Transfer factors:

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

Pros:

- Main syst. Uncertainties partially cancel in ratio

Cons:

- Requires a full study of possible syst. sources (theory)

Targets: the main irreducible backgrounds (top, VB+jets)

Pure MC

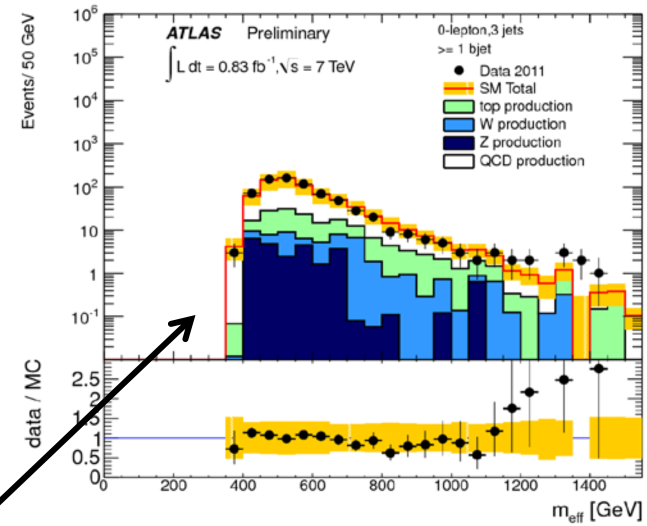
Targets: well suited for small backgrounds (VV)

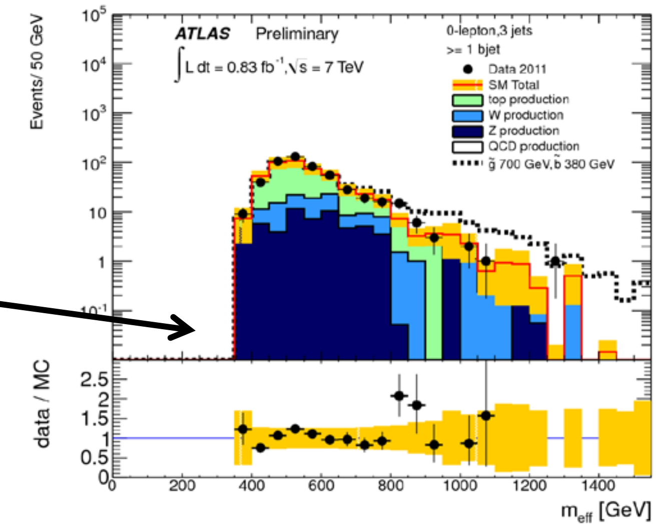
✓ There are no general rules in term of bkg treatment
✓ Dealing with a background process is analysis dependent

Background estimation methods, examples

« Fully » data-driven estimate: QCD in 0-lepton (+bjet) + MET + jets channels - Jet smearing method

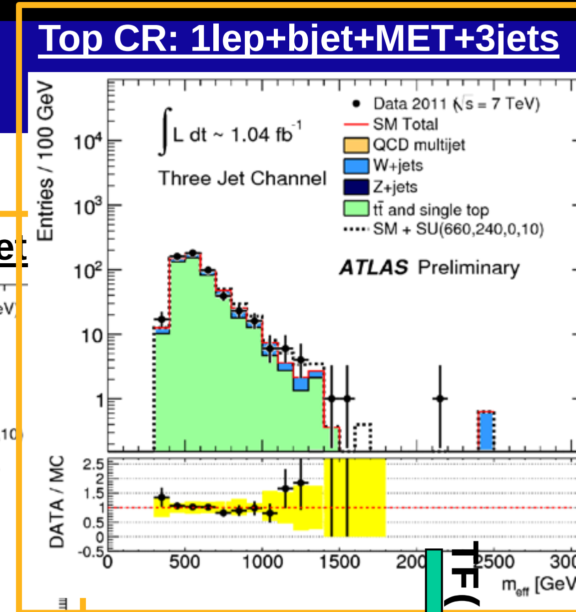
1. **Determine the jet response function R from dijet balance and 3-jets mercedes events**
2. **Take a control sample of multijets events with small MET.**
3. **Smear each jet by its response R**
4. **Normalize the shape obtained in a QCD enhanced region with low $\Delta\phi(\text{jet}, E_T^{miss})$ < 0.4**
5. **Propagate to SR**

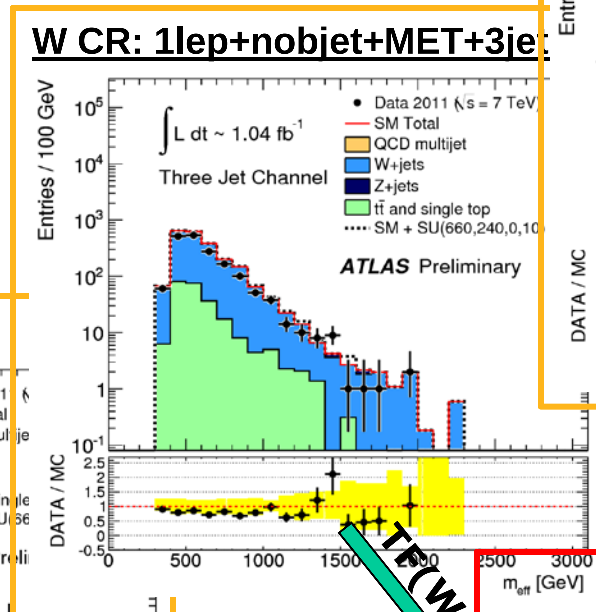


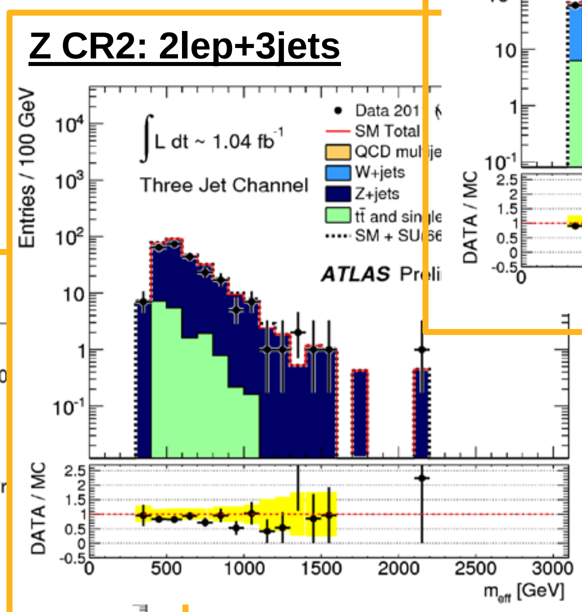


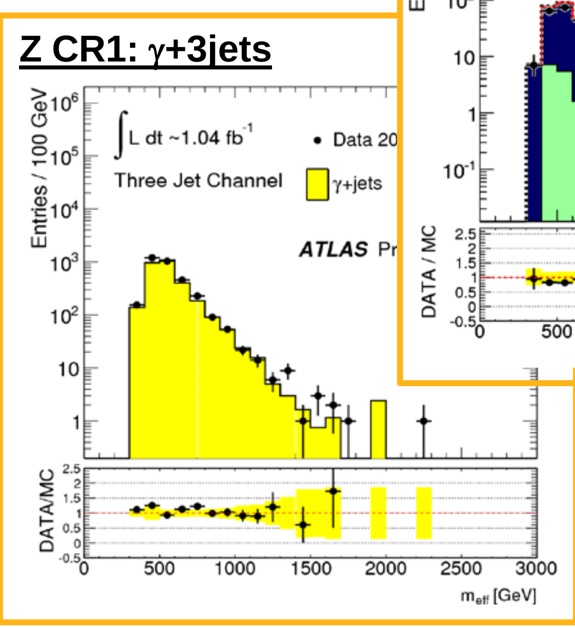
Background estimation methods, examples

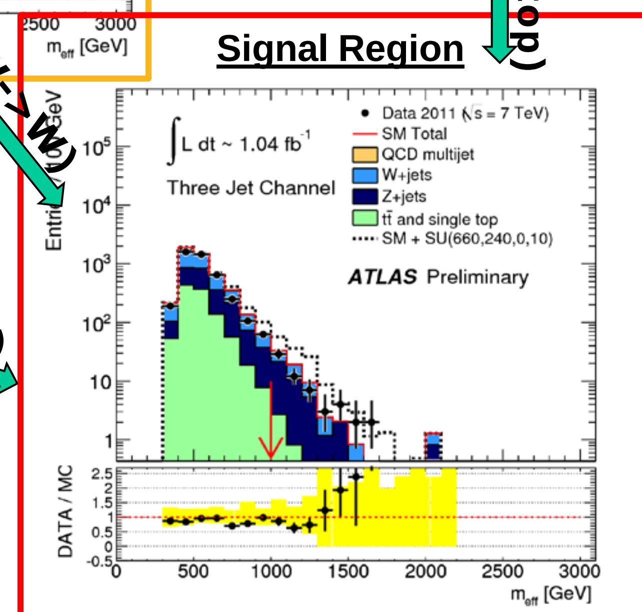
Semi data-driven estimate : 0-lepton + MET + 3-jets channel











Statistical tests

Fill all useful information into a global likelihood

$$L = P_{Signal} \times P_{Top} \times P_W \times P_{QCD} \times \prod P_{Syst}$$

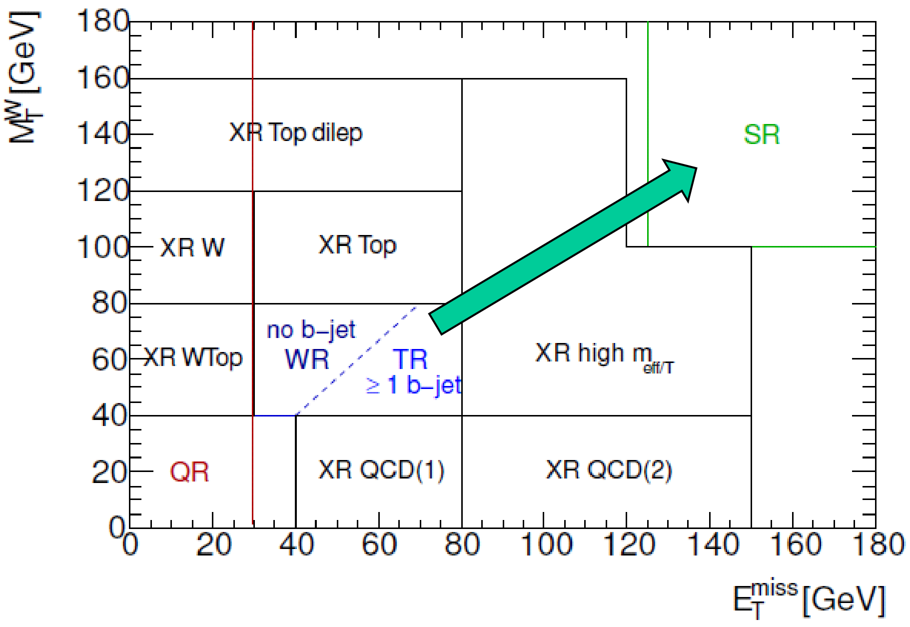
- **One poisson for signal region and per control region**
  - $\Rightarrow$ **Simultaneous fit of all regions**
- **Systematic uncertainties treated by nuisance parameters**
  - $\Rightarrow$ **Correlations treated properly**

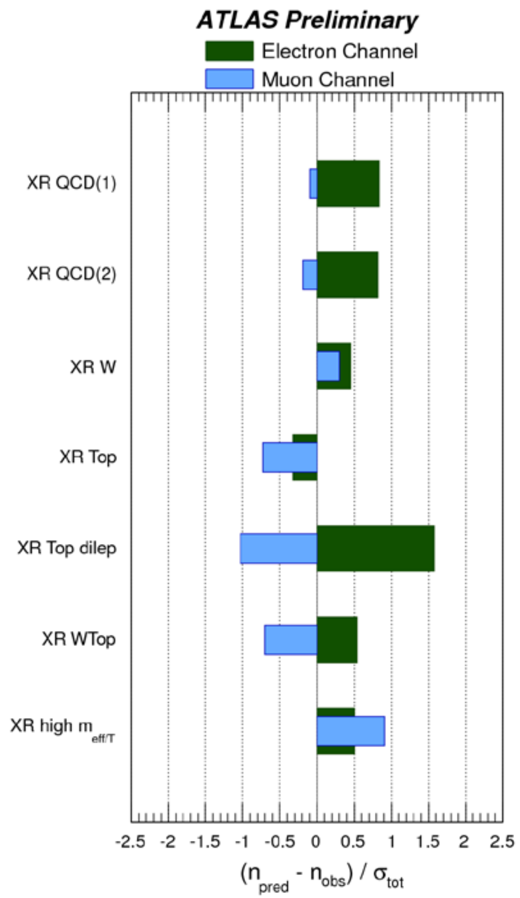
Perform tests via:

- **A LLR test statistics**
- **Toys MC to determine LLR p.d.f**
- **p-value p_b for bkg only hypothesis**
- **(one-sided) $CL_s = p_{s+b}/(1-p_b)$ for exclusion limits**

Validating the background estimates

- ✓ **Since aiming for discovery, must provide robust estimates**
- ✓ **Compare predictions to observation in « validation » regions:**
  - o **close in phase space to final signal region (but wo too much signal !)**
  - o **dedicated to each specific background process**





✓ **Systematizing this approach to all ATLAS SUSY searches**
✓ **Tells us also if we underestimate / overestimate our uncertainties**

SUSY signatures summary

Signatures	Search goals	Current status
0-lepton + MET + ≥2,3,4jets	Heavy coloured particles decaying semi-invisibly with large mass splitting	1 fb^{-1} (preliminary) ATLAS-CONF-2011-086
0-lepton + MET/$\sqrt{H_T}$ + ≥6,7,8 jets	Long decay chains	1 fb^{-1} (preliminary) Paper soon
1-lepton + MET + ≥3,4 jets	• Smaller mass splitting than 0-lepton • Intermediate decays to charginos	1 fb^{-1} (preliminary) ATLAS-CONF-2011-090
0-lepton + MET + ≥1 b-jet + ≥3 jets	Gluino and 3rd gen. squarks decaying to heavy flavors	0.8 fb^{-1} ATLAS-CONF-2011-098
1-lepton + MET + ≥1 b-jet + ≥4 jets		1 fb^{-1} ATLAS-CONF-2011-130
2-leptons OS	• Weak gauginos and sleptons intermediate decays • Direct gaugino production	1 fb^{-1} (preliminary) Paper soon
2-leptons SS		
2-leptons OS SF		
multileptons	Direct gaugino production, GMSB, RPV gaugino decays	35 pb^{-1} ATLAS-CONF-2011-039
γγ + MET	GMSB with neutralino NLSP	1 fb^{-1} (preliminary) arXiv:1107.0561

Exotics signatures summary

Signatures	Search goals	Current status
monojet + MET	**Large Extra Dimensions (ADD)**	1 fb^{-1} ATLAS-CONF-2011-096
$\gamma\gamma$ + MET	**UED**	1 fb^{-1} (preliminary) arXiv:1107.0561
Top pairs + MET	**Fourth generation quark**	1 fb^{-1} (preliminary) Paper soon

Results and interpretations

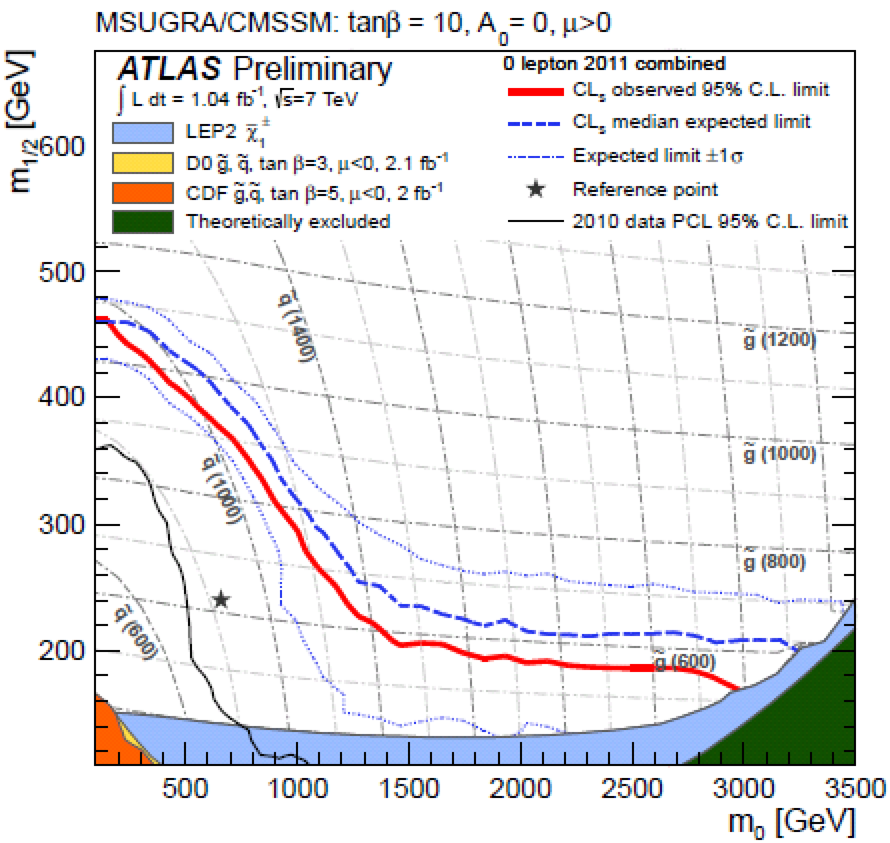
1. Top-down approachs: SUSY breaking models

2. Bottom-up approachs: SUSY simplified models

3. Exotics models

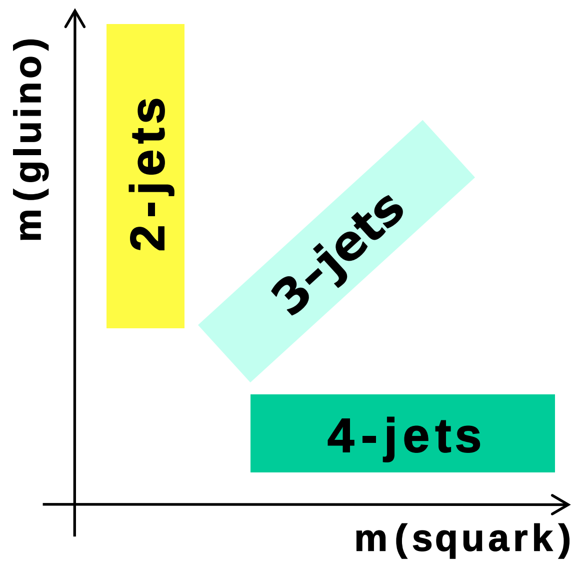
mSUGRA / CMSSM

✓ **mSUGRA/CSSM (A_0=0, tan(β)=10, μ>0)**



✓ **Best limits obtained in 0-lepton channels**

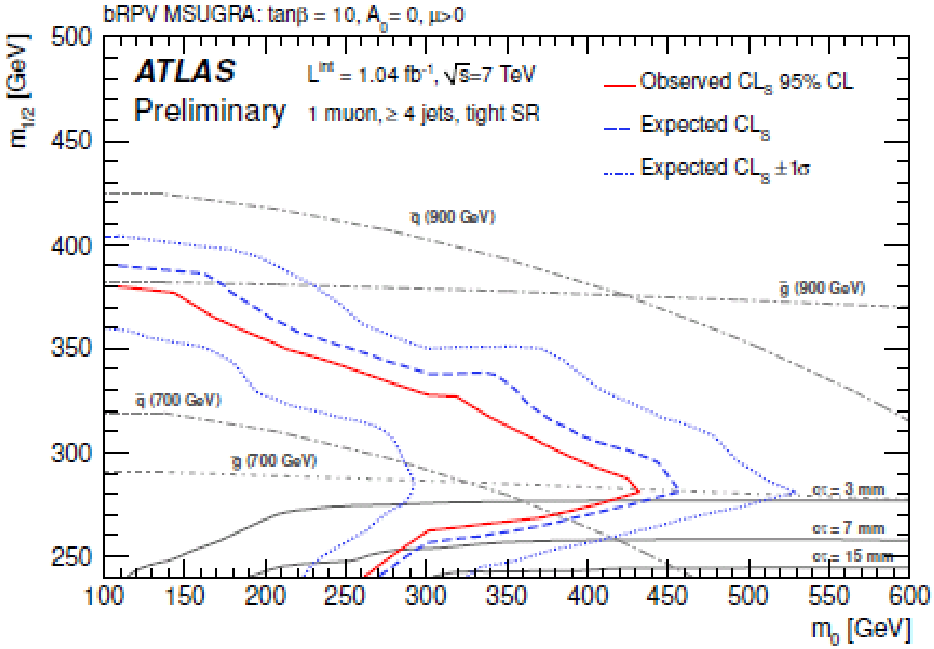
✓ **High m_0 region benefits from new high jet multiplicities channels**



✓ **Equal squark-gluino masses excluded below 980 GeV**

bRPV mSUGRA / CMSSM

Study bilinear R-Parity Violating model inducing a mixing between neutrinos and neutralinos



✓ **bilinear parameters determined from neutrino mixing data**

✓ **neutralino decays into neutrinos + possibly muon or tau (electron decay is highly suppressed)**

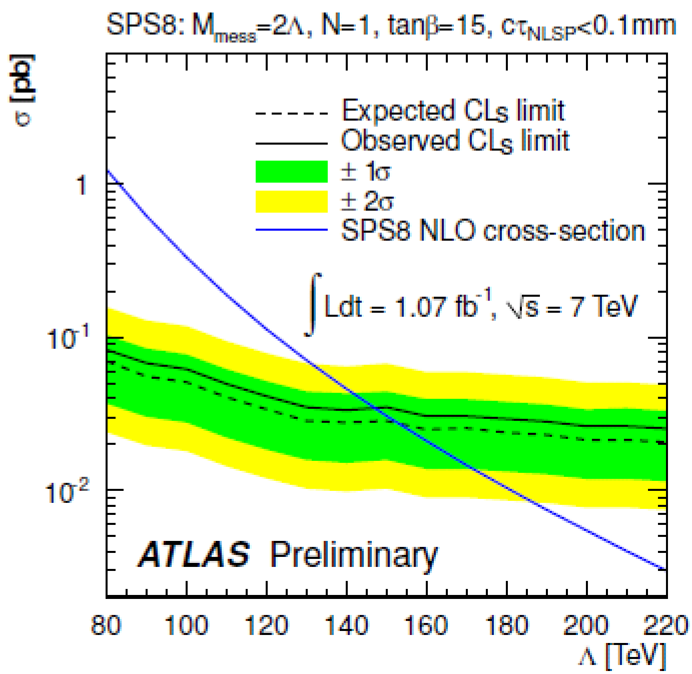
✓ **Look at prompt decays (cτ < 15 mm) in 1-muon + MET + jets channel**

GMSB

Search performed in γγ + MET channel

- ✓ neutralino NLSP (mainly bino-like)
- ✓ prompt decays cτ < 0.1 mm

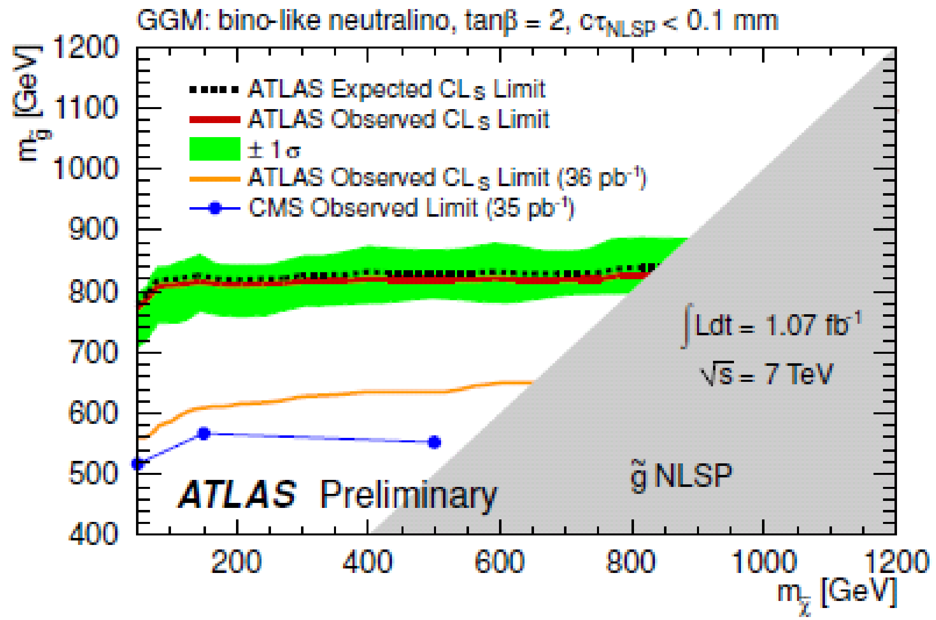
Minimal GMSB scenario Snowmass point slopes



- ✓ σ < 0.03 – 0.08 pb
- ✓ Excluding Λ < 145 TeV

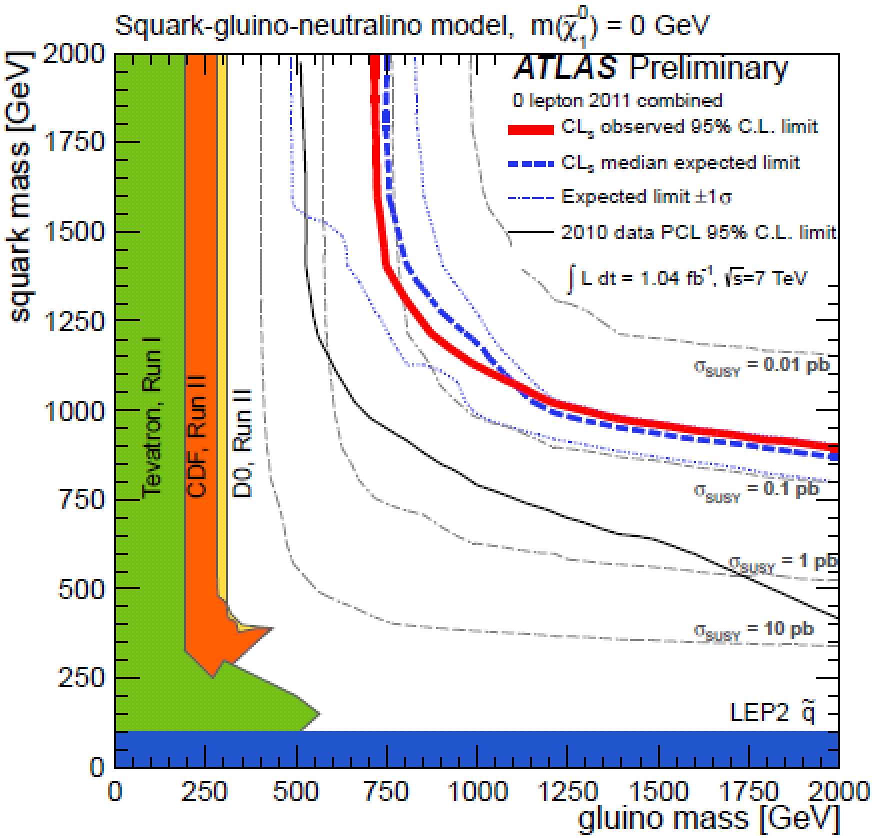
General Gauge Mediation (GGM)

- No hierarchy between masses
- Other masses set to 1.5 TeV



- ✓ σ < 0.02 – 0.04 pb ($m(\tilde{\chi}_1^0) = 150\,\mathrm{GeV}$)
- ✓ Excluding gluino mass < 776 GeV

Simplified models – gluino and squarks



Assumptions:

✓ All masses set to 5 TeV except
- o **neutralino1,**
- o **gluino,**
- o **degenerated 1st & 2d generation squarks**

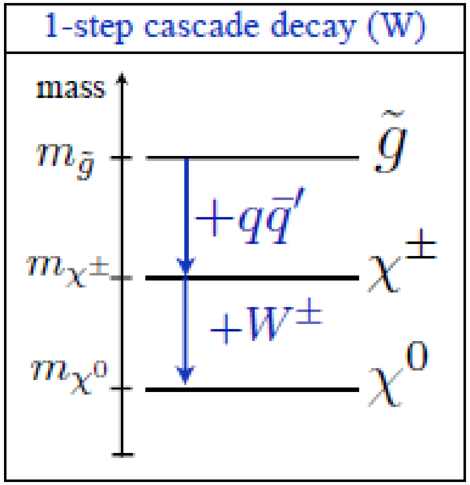
✓ Large mass splitting limit:
- o **LSP mass set to 0.**
- o **results roughtly unchanged for m(LSP) up to 200 GeV.**

✓ **Equal squark-gluino masses excluded below 1075 GeV**

Simplified models – Decays with intermediate charginos

- ✓ **Following models proposed in D. Alves et al. arXiv1105.2838**

- ✓ **Assume all squark masses are heavy except**
  - o **gluino XOR squark (1st or 2d gen.only)**
  - o **LSP neutralino1**
  - o **Intermediate chargino**



- ✓ **2 possible decay chains:**
  - o $\tilde{g} \to q\bar{q}\tilde{\chi}_1^\pm \to q\bar{q}W\tilde{\chi}_1^0,$

    $x = (m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0))/(m(\tilde{g}) - m(\tilde{\chi}_1^0))$
  - o $\tilde{q} \to q'\tilde{\chi}_1^\pm \to q'W\tilde{\chi}_1^0,$

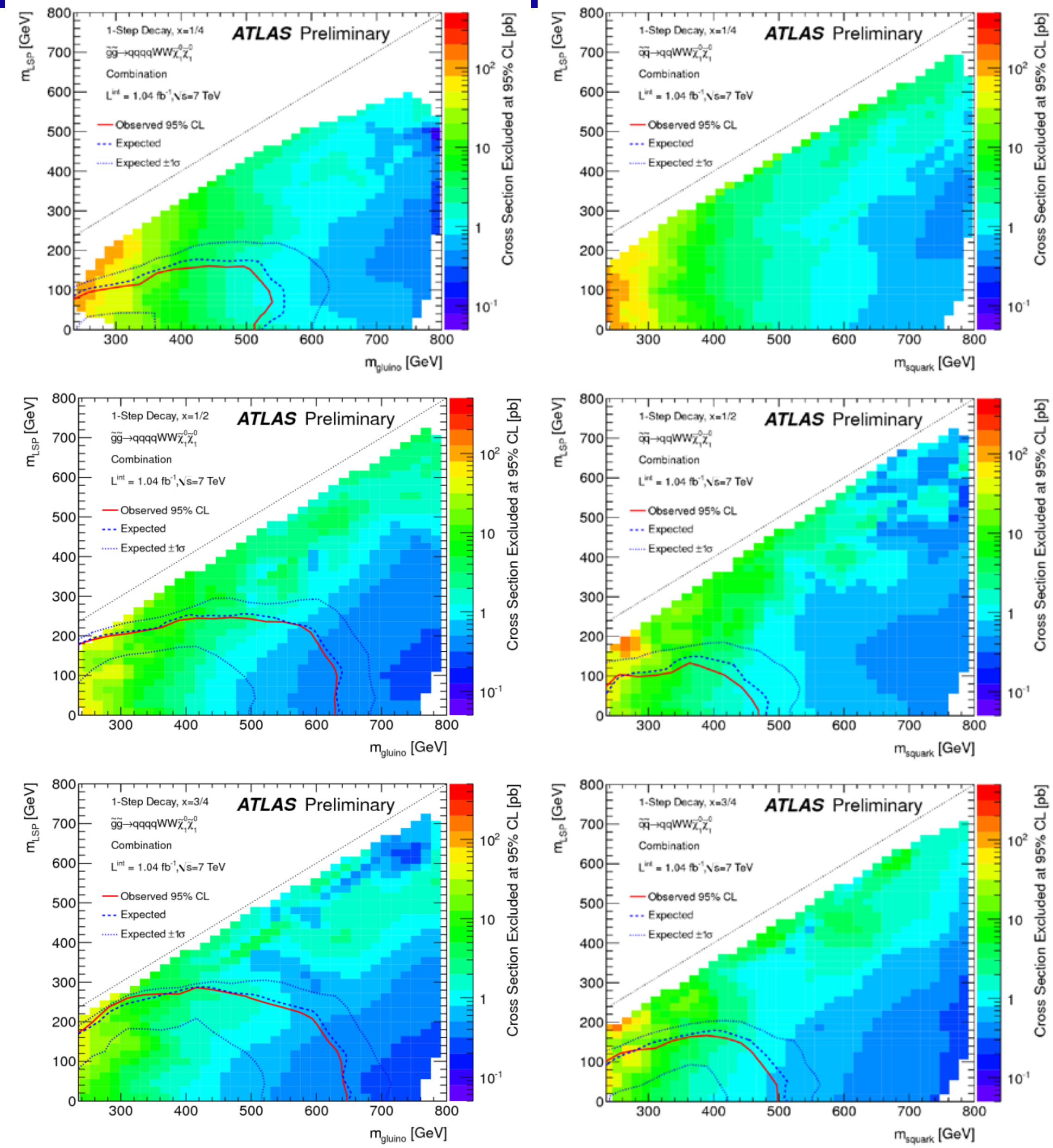
    $x = (m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0))/(m(\tilde{q}) - m(\tilde{\chi}_1^0))$

- ✓ **Predictions are**
  - o **compared to data in 1-lepton + MET + ≥3,4 jets channels**
  - o **interpreted in (m(gluino),m(LSP)) plane for different values of x**

Simplified models – Decays with intermediate charginos

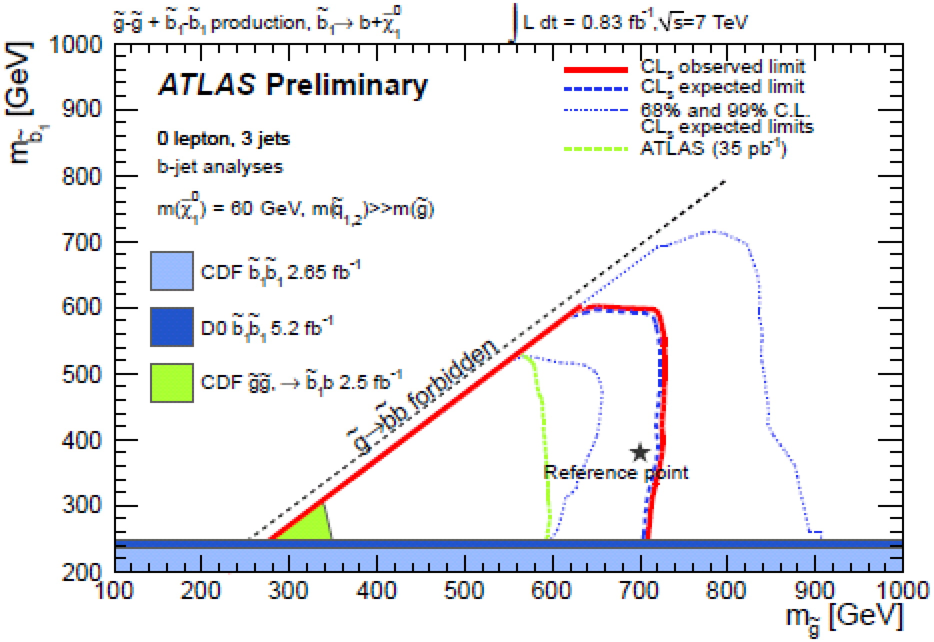
1-lepton + MET + ≥3,4 jets

For gluino model and x>1/2, LSP masses < 200 GeV are excluded for m(gluino) < 600 GeV



Simplified models – gluino and 3rd generation squarks

0-lepton + MET + ≥1 b-jet + ≥3 jets



Excluded:

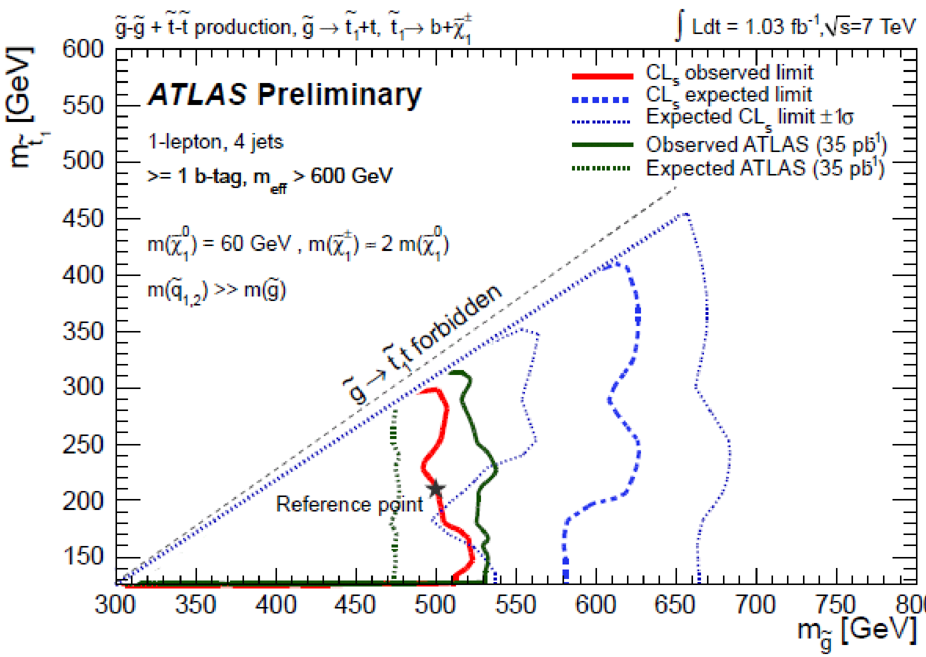
- m(gluino) < 720 GeV if m(sbottom) < 600 GeV
- m(gluino) < 500 GeV if m(stop) < 300 GeV

Assumptions:

✓ All masses set to 5 TeV except
- o gluino,
- o 3rd generation squarks,
- o LSP
- o $Br(\tilde{g} \rightarrow \tilde{b}_1 b) = 100\%$ or $Br(\tilde{g} \rightarrow \tilde{t}_1 t) = 100\%$

✓ Large mass splitting:
- o LSP mass set to 60 GeV
- o $Br(\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}) = 100\%, m(\tilde{\chi}_1^{\pm}) = 2 \cdot m(\tilde{\chi}_1^{0})$

1-lepton + MET + ≥1 b-jet + ≥4 jets



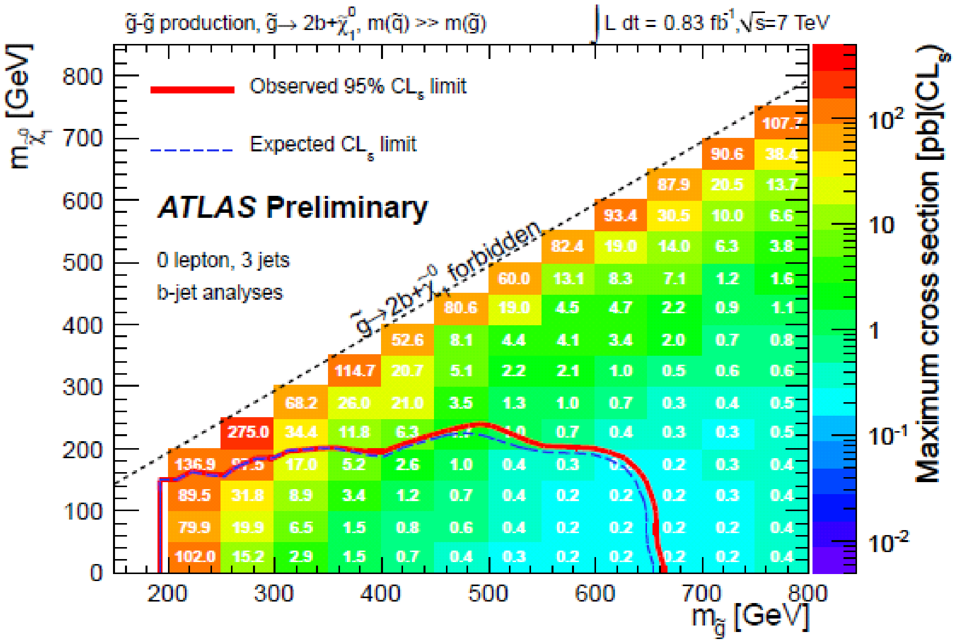
Simplified models – Gluino Decays to Heavy Flavor

✓ **Model inspired from arXiv1105.2838 model B.000**

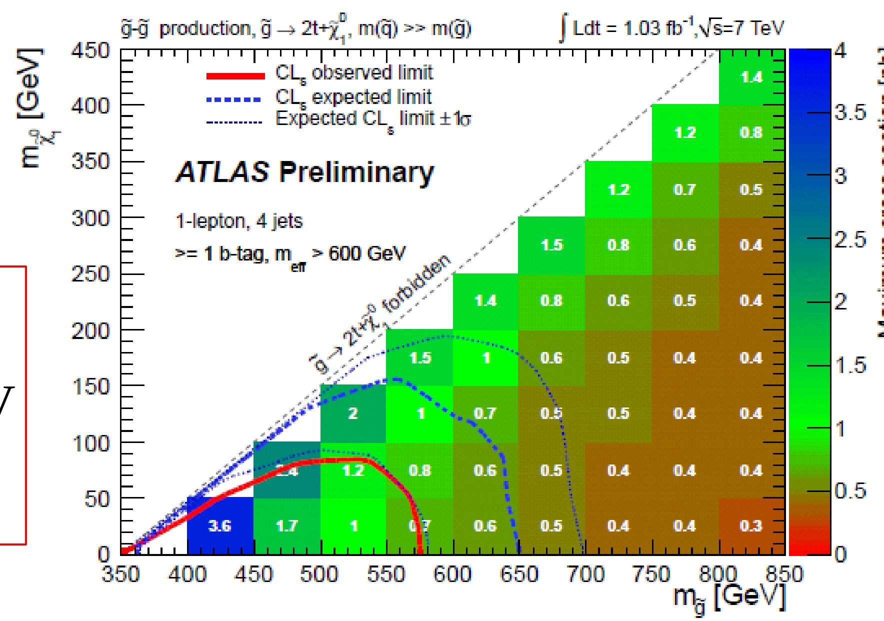
✓**All squark masses are heavy**
- **off-shell gluino decays**
- $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ or $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$

✓ **Results are interpreted in (m(gluino),m(LSP)) plane**

0-lepton + MET + ≥1 b-jet + ≥3 jets



1-lepton + MET + ≥1 b-jet + ≥4 jets



Excluded:
- **g→b-decays: m(LSP) < 200-250 GeV when m(gluino) < 660 GeV if $\Delta M(\tilde{g} - \tilde{\chi}_1^0) > 100$ GeV**
- **g→t-decays: m(LSP) < 40 (80) GeV when m(gluino) < 570 (540) GeV**

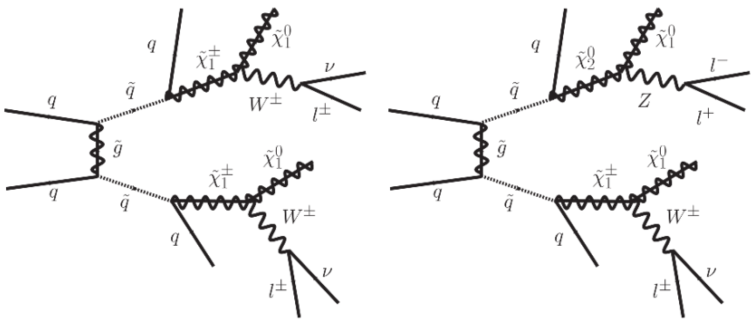
Assumptions

✓ strong pair production (squarks)

✓ Decaying to neutralino LSP via gauginos

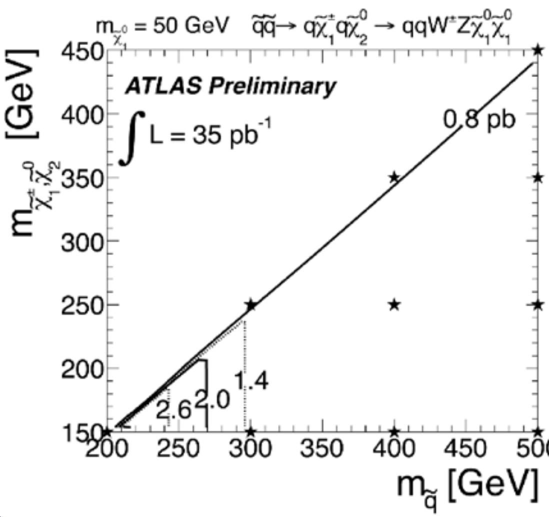
✓ Mass hierarchy:

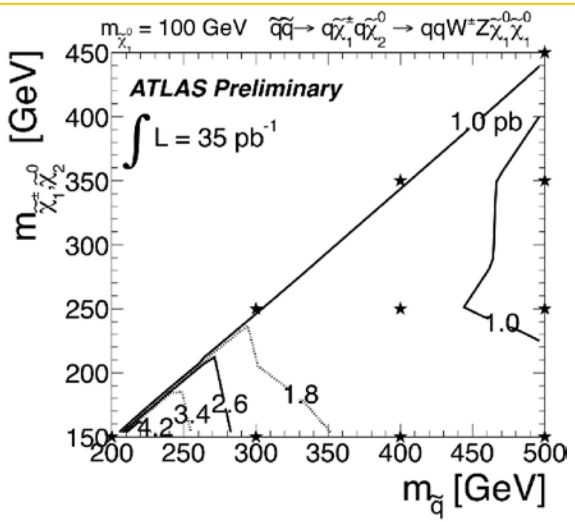
$$m(\tilde{q}) > m(\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}) > m(\tilde{\chi}_1^0)$$

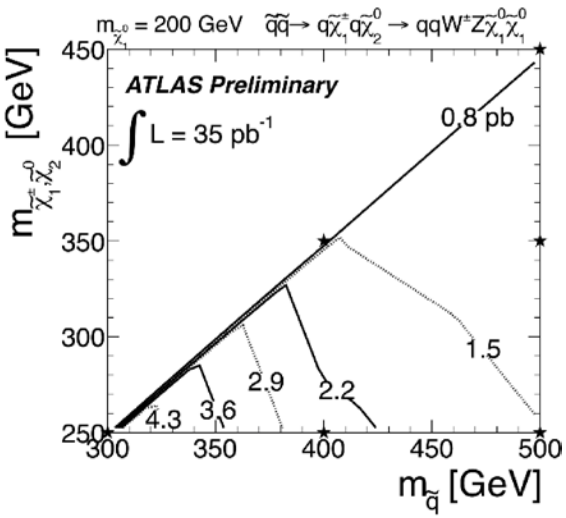


✓ Results are interpreted in (m(squark),m(chargino)) plane for different values of m(LSP)

✓Set limits on σ×Br using data from 2-lepton SS channel with 35 pb-1



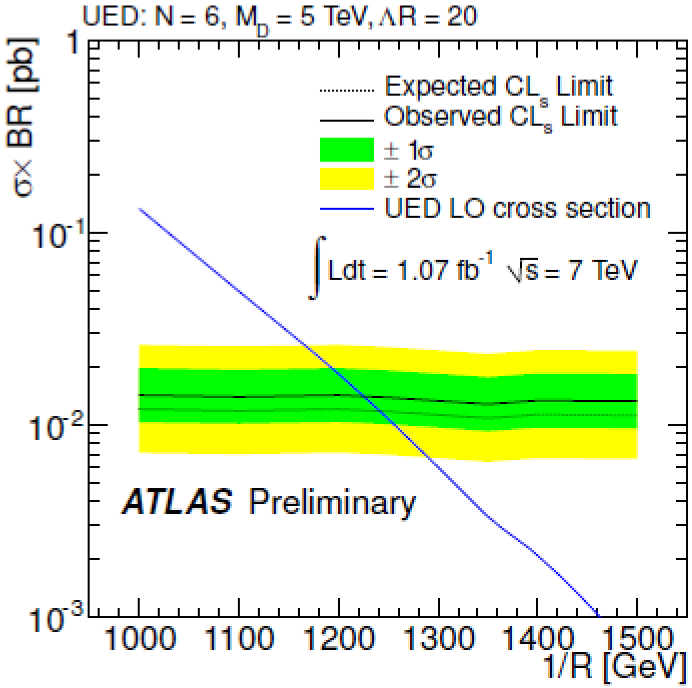




Non-SUSY models: extra dimensions

Universal Extra Dimensions (UED)

- LKP decay: $\gamma^* \to G + \gamma$
- $\gamma\gamma$ + MET channel

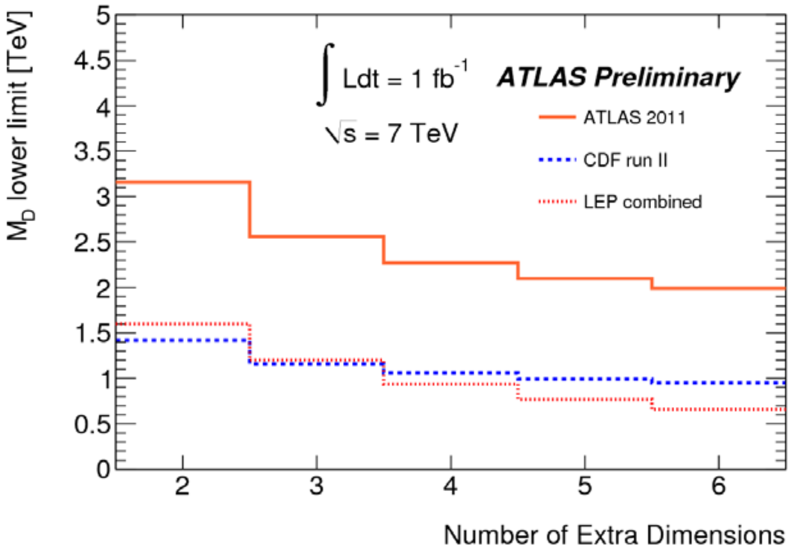


✓ σ < 0.015 – 0.027 pb

✓ Excluding 1/R < 1224 GeV

Large Extra Dimensions (ADD)

- Monojet + MET channel



✓ Fiducial σ < 0.045 – 2.02 pb

✓ Excluding M_D < 2.0 – 3.2 TeV

Non-SUSY models: fourth generation up quark

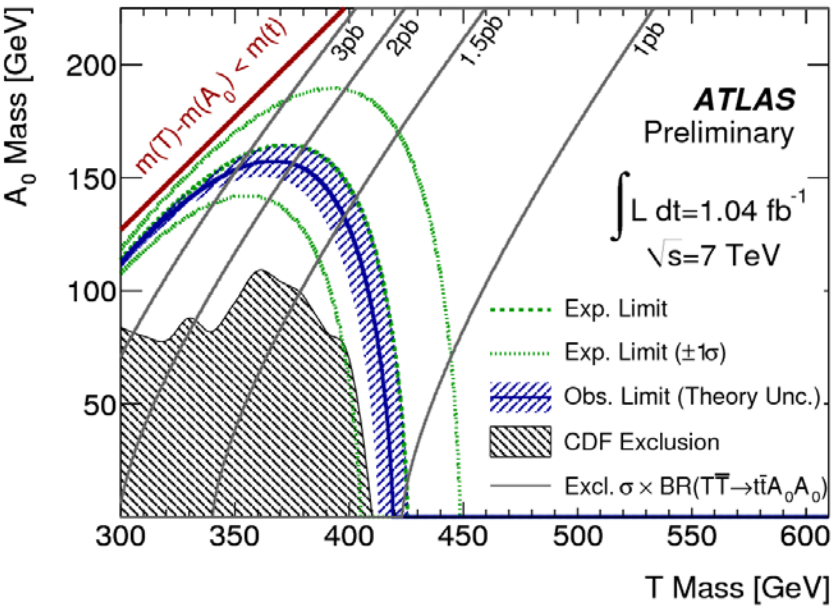
✓ **Pair produced exotic top partner T decaying to neutral particle A_0**

$$T\overline{T} \rightarrow t\bar{t} + A_0 + A_0$$
$$\rightarrow l\nu\nu\overline{q}b\overline{b}$$

✓ **Model interpreted in 1-lepton + MET + jets channel**

Exclude
✓ **T masses up to 420 GeV**
✓ **A_0 masses up to 140 GeV**

✓ **σ < 1.1pb m(T)=420 GeV, m(A_0)=10 GeV**



Limits

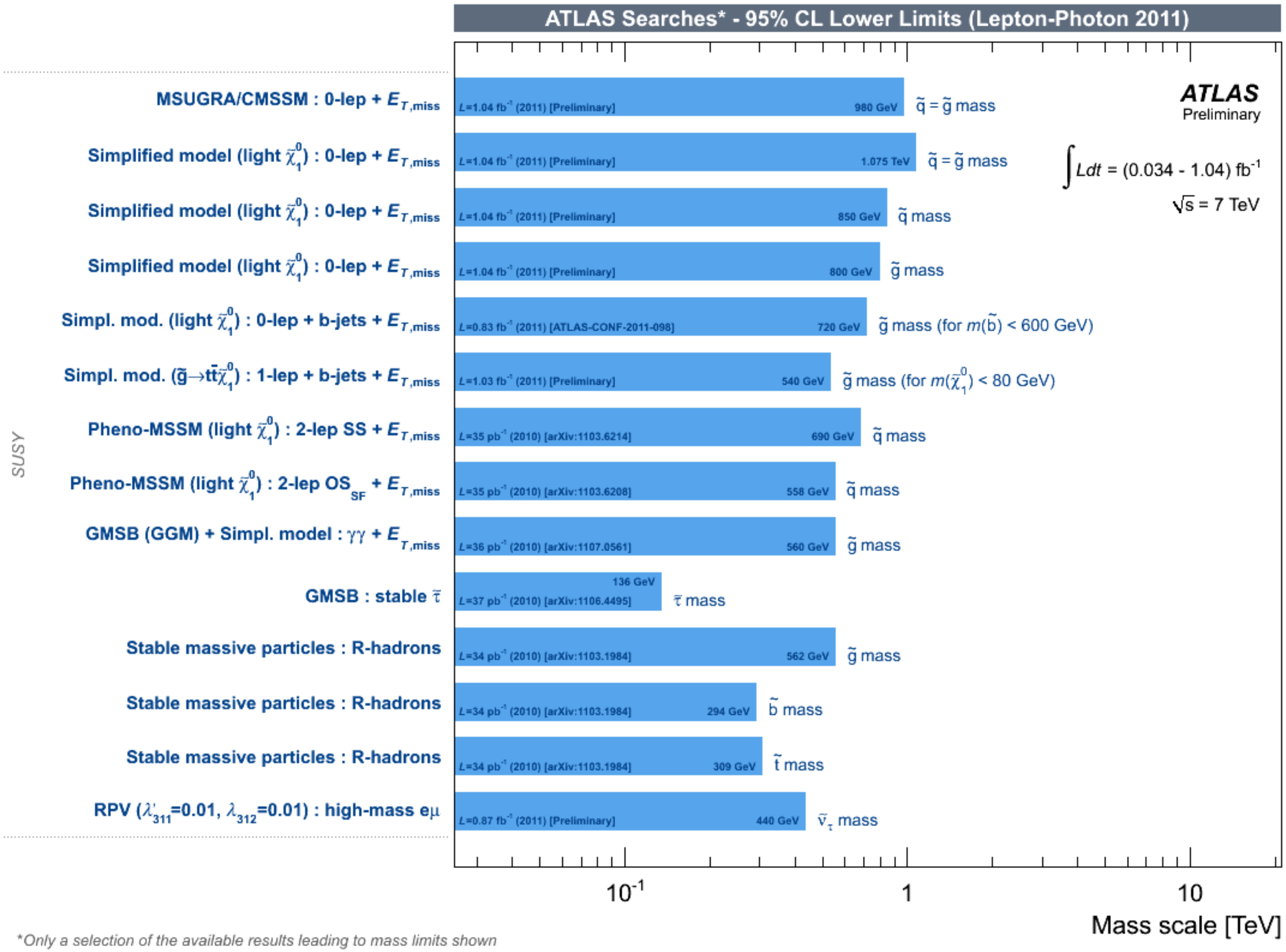
- **None of the channel studied observes a significant excess**
  - ⇒ **Set upper limits on fiducial cross-section σ×A×ε**
  - ⇒ **Can be used to set first order limits for your own model**
  - ⇒ **Lot of extra information on published distributions can be found on HepData**

- **Model independent limits on identical flavor excess in OS dileptonic channels**

$$\mathcal{S} = \underbrace{\frac{N(e^{\pm}e^{\mp})}{\beta(1-(1-\tau_e)^2)}}_{\text{SF}} - \underbrace{\frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_\mu)}}_{\text{DF}} + \underbrace{\frac{\beta N(\mu^{\pm}\mu^{\mp})}{(1-(1-\tau_\mu)^2)}}_{\text{SF}}$$

Signal Region	FS-SR1	FS-SR2	FS-SR3
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	80	80	250
Number jets	≥ 2	-	-
m_{ll} veto [GeV]	-	80-100	-

	$\mathcal{S} > \mathcal{S}_{obs}$ (%)	Limit $\bar{\mathcal{S}}_s$ (95% C.L.)
FS-SR1	46	88
FS-SR2	7	156
FS-SR3	77	4.9



ATLAS SUSY searches typically probe masses ~ 500 – 1000 GeV

Short-term plans

How can we go on ?

A few facts

- ✓ No excess found till now
- ✓ Expect new results with ~ x10 more statistics by end of year

⇒ **Little gain in term of mass reach for channels we already cover**

⇒ **But lot of room for**

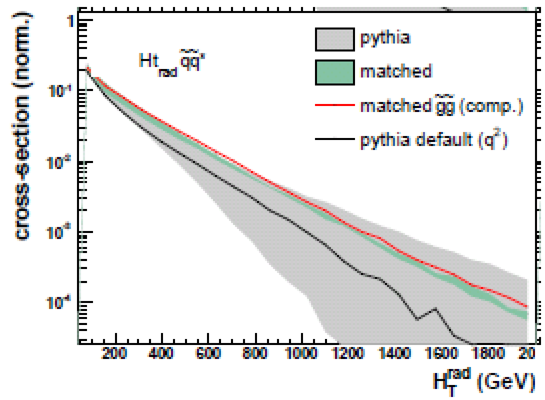
- **New interpretations with existing channels**
- **Try new signatures**

Existing signatures

Many analysis start to be mature => improve methods to extract results

- **Using shape information**
  - bins in m_{eff}, n_{jets}
  - combining different channels
- **Tackling the main systematic uncertainties**
  - Theory uncertainties on backgrounds
- **Improve ISR treatment for SUSY processes**
  - Crucial for compressed spectrums
  - Move to Madgraph for simplified models

J. Alwall et al. JHEP 0902:017,2009
arXiv:0810.5350



Extend interpretations of existing signatures

- **0-lepton + MET + jets channels**
  - Simplified models: gluino and squark production with direct or 1-step cascade decay
  - UED or simplified models with heavy quarks and gluons partners
- **Monojet +MET**
  - Squark-neutralino direct production ?

New signatures – example 3rd generation squarks searches

Expect 3rd generation squark to be lighter due to mixing

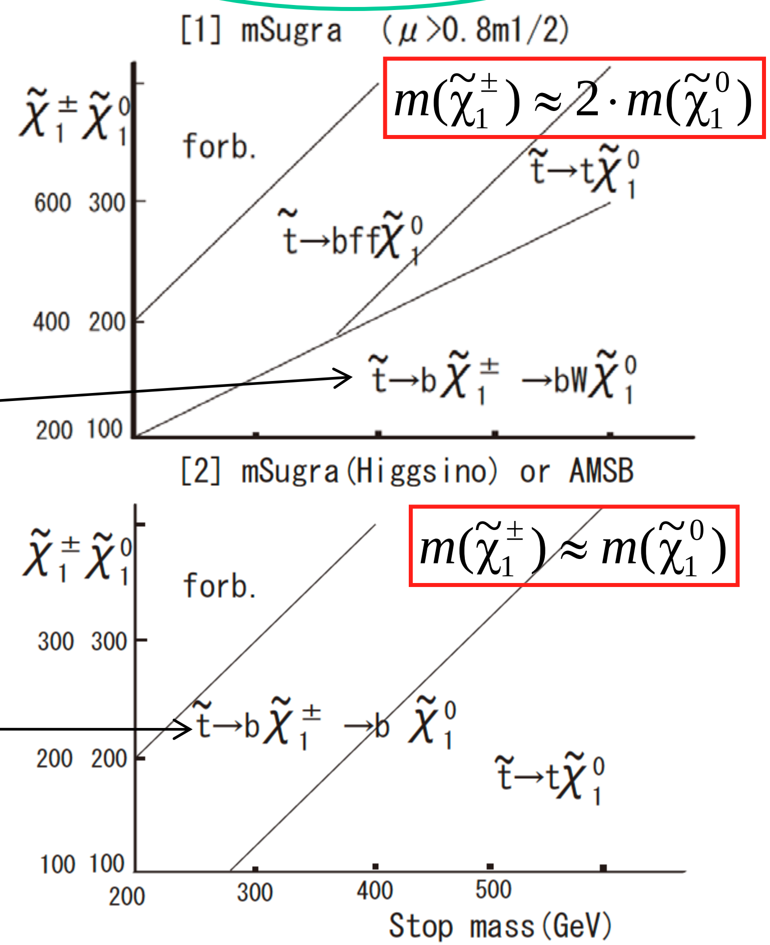
$$m^2(\tilde{t}_{1,2}) = \frac{1}{2}\left[m^2(\tilde{t}_R) + m^2(\tilde{t}_L)\right] \mp \frac{1}{2}\sqrt{\left[m^2(\tilde{t}_R) - m^2(\tilde{t}_L)\right]^2 + 4m^2(t)\left[A_t - \mu \tan\beta\right]^2}$$

Currently public with 1 fb^{-1}

- **0-lepton + MET + ≥1 b-jet + ≥ 3jets**
- **1-lepton + MET + ≥1 b-jet + ≥ 3jets**

Extend searches to

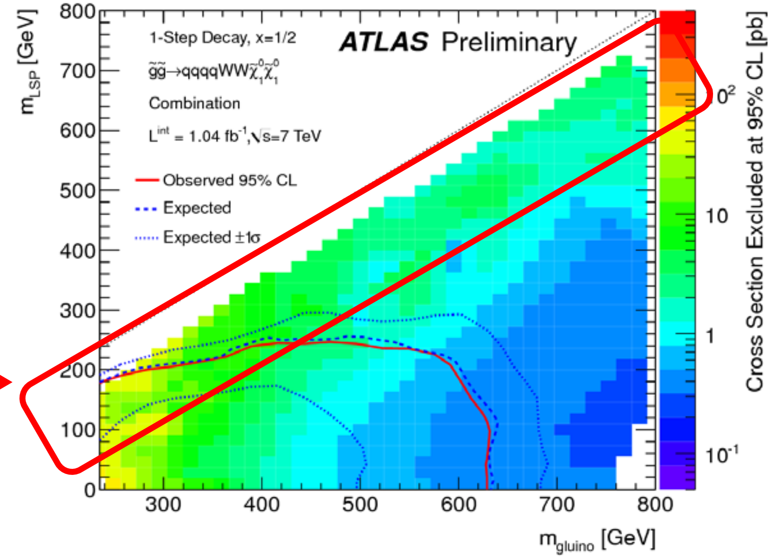
- **2 b-jets + 2 OS leptons channel**
  - ⇒ **direct stop production**
- **2 b-jets exclusive channel**
  - ⇒ **direct sbottom production,**
  - ⇒ **direct stop production with very small** $\Delta M(\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^{0})$



Other new signatures of interest

New types of signatures being studied now

- **(hadronic) tau channels + MET**
  - – 1-tau + MET + jets
  - – 1-tau + 1-lepton + MET
  - – 2-taus + MET
  - ⇒ GMSB stau NLSP



- **Soft-leptons + jets + MET**
  - ⇒ compressed spectrums

- **Multileptons + MET**
  - ⇒ RPV models
  - ⇒ GMSB co-NLSP
  - ⇒ Direct gaugino / sleptons productions

- **Signatures motivated by general gauge mediation**
  - ⇒ Z+MET
  - ⇒ γ+lepton+MET

Conclusion

- ~10 ATLAS analysis based on MET and with ~ 1 fb^{-1} data have published new results since winter conferences
- No significant excess found yet
- => Set limits on a variety of models
  - Provide upper limits on expected number of events in each channel studied
  - Moving progressively toward simplified models interpretations attached to a specific signature
  - Is that useful ??
- New signatures will appear as
  - our understanding of detector improves
  - we are chasing SUSY/Exotics models at 7 TeV more and more in non-obvious channels