Inclusive gluinos and squarks searches at ATLAS

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Argonne National Laboratory

LPC Near Future SUSY Search
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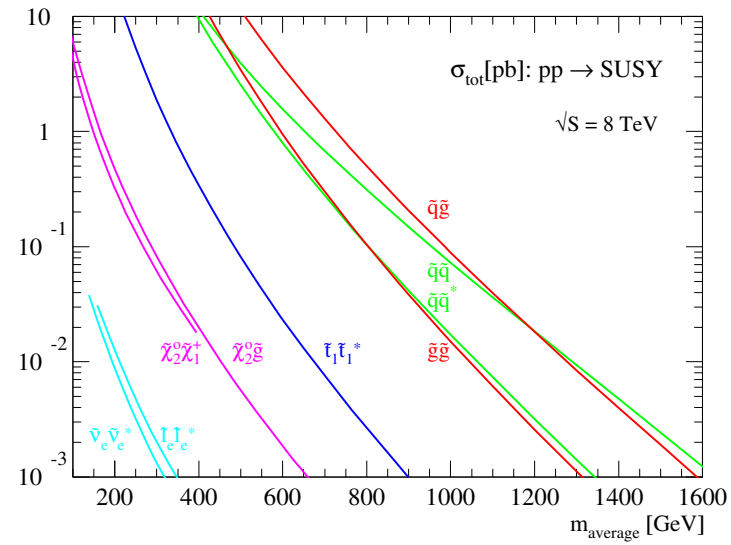
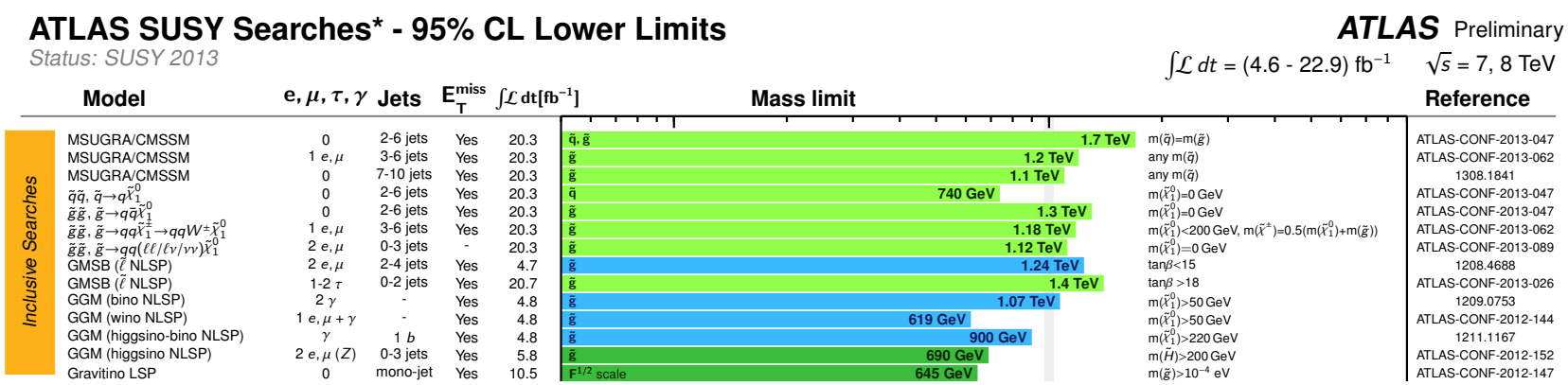
Introduction

- Motivation of SUSY
  - Higgs mass stabilization (hierarchy problem)
  - Unify of gauge couplings
  - Dark matter candidate
- Strong gluino and squark production is attractive due to high cross section



- Around 4.8 fb^{-1} (7 TeV) and 20 fb^{-1} (8 TeV) have been analyzed



Outline:

- Search Strategy
- 0lepton+2-6 jets
- 0lepton + multijets
- Search with leptons
  - 1 hard lepton + jets + MET
  - 1 soft lepton + jets + MET
  - 2 same sign leptons + jets + MET
- Search for R-hadron
- Interpretation of search results

Search Strategy

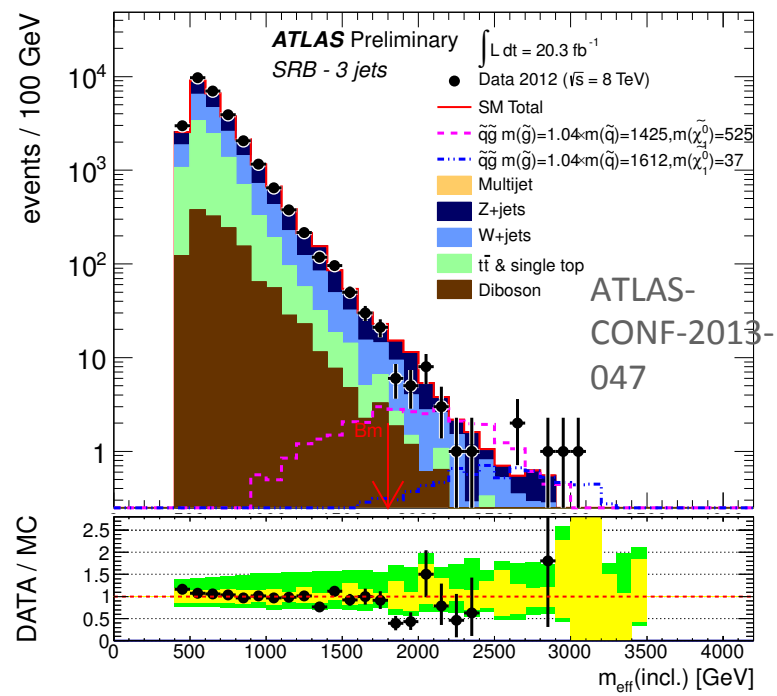
- Define model-dependent signal regions:
  - Number of jets from 2 to 10, with or without leptons (no taus) and MET.
  - Jets can be identified as "fat" jet in some cases
  - Model-dependent optimization for the best reach
- Perform a likelihood fit combining signal regions and corresponding control regions to find excess or to exclude the model parameter space.
- Main variables used to distinguish signal from backgrounds
  - Missing transverse energy
  - Transverse mass

$$m_T = \sqrt{2 \cdot p_T^{\ell} \cdot \not{E}_T \cdot (1 - \Delta\phi)}$$

  - Effective mass

$$m_{eff} = \not{E}_T + \sum_j p_T^{jet} \; (+ \sum_\ell p_T^{\ell})$$

  - Razor variable



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0-lepton + 2-6 jets Analysis

- Wide catch of SUSY hadronic decay chains with 2-6 jets and MET
- Signal region definitions

Squark-squark | Squark-gluino | gluino-gluino

Requirement	Channel									
	A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
	L	M	M	T	M	T	–	L	M	T
E_T^{miss}[GeV] >	160									
$p_T(j_1)$ [GeV] >	130									
$p_T(j_2)$ [GeV] >	60									
$p_T(j_3)$ [GeV] >	–		60		60		60	60		
$p_T(j_4)$ [GeV] >	–		–		60		60	60		
$p_T(j_5)$ [GeV] >	–		–		–		60	60		
$p_T(j_6)$ [GeV] >	–		–		–		–	60		
$\Delta\phi(\text{jet}_i, \mathbf{E}_T^{miss})_{min}$ >	0.4 ($i = \{1, 2, (3 \text{ if } p_T(j_3) > 40 \text{ GeV})\}$)				0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T > 40$ GeV jets)					
$E_T^{miss}/m_{eff}(Nj)$ >	0.2	–[a]	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
m_{eff}(incl.) [GeV] >	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

(a) For SR A-medium the cut on $E_T^{miss}/m_{eff}(Nj)$ is replaced by a requirement $E_T^{miss}/\sqrt{H_T} > 15$ GeV$^{1/2}$.

- Major backgrounds: W+jets, Z+jets, top quark pairs, single tops, QCD multijets

0-lepton + 2-6 jets: Background Estimation

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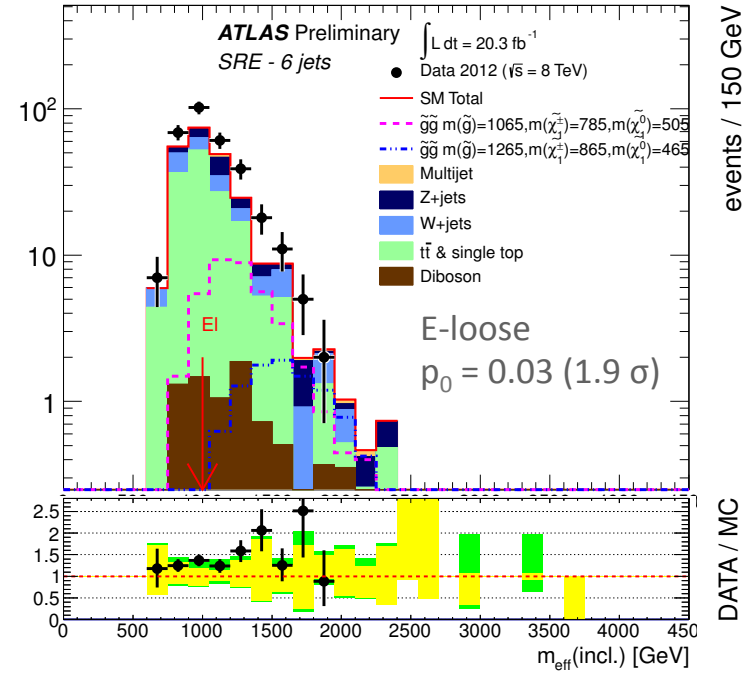
- Define 4 CRs for each SR: only one background process is dominant in the CR

CR	SR background	CR process	CR selection
CRY	$Z(\to \nu\nu)$+jets	γ+jets	Isolated photon
CRQ	multi-jets	multi-jets	Reversed $\Delta\phi(\text{jet}, \mathbf{E}_T^{\text{miss}})_{\text{min}}$ and $E_T^{\text{miss}}/m_{\text{eff}}(Nj)$ requirements[a]
CRW	$W(\to \ell\nu)$+jets	$W(\to \ell\nu)$+jets	$30\text{ GeV} < m_T(\ell, E_T^{\text{miss}}) < 100\text{ GeV}$, b-veto
CRT	$t\bar{t}$ and single-t	$t\bar{t} \to bbqq'\ell\nu$	$30\text{ GeV} < m_T(\ell, E_T^{\text{miss}}) < 100\text{ GeV}$, b-tag



- Roughly speaking, extrapolating the backgrounds from CRs to SR using transfer factors:
  - Transfer factor is the ratio of a background process between CR and SR.
- Do the job smarter: extract the backgrounds using likelihood fit with transfer factors as inputs.

Diboson	5.5 ± 2.1
Z+jets	12 ± 7
W+jets	18 ± 7
Ttbar+single top	76 ± 19
Multijet	1.0 ± 1.0
Total backgrounds	113 ± 21
Observed events	166

Long decay chains: 0lepton + 7 to 10 jets + MET

- 19 signal regions are defined:
  - p_T > 50 GeV: 8, 9 and 10 or more jets with 0, 1 or at least 2 jets identified as b-jets
  - p_T > 80 GeV: 7 and at least 8 jets with 0, 1 or at least 2 jets identified as b-jets
  - p_T > 50 GeV and M_J^Σ > 340 or 420 GeV, number of jets are at least 8, 9 or 10
    - The M_J^Σ is the scalar sum of "fat" jets reconstructed from clustering narrow jets (0.4 cone) within R=1 cone.

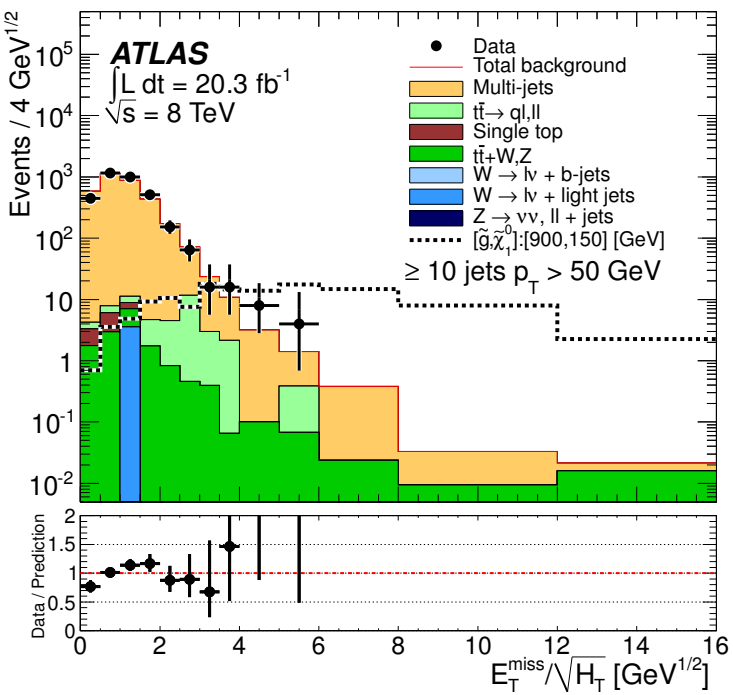
Discriminant variable: $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ > 4 GeV^{-2} is applied for all regions

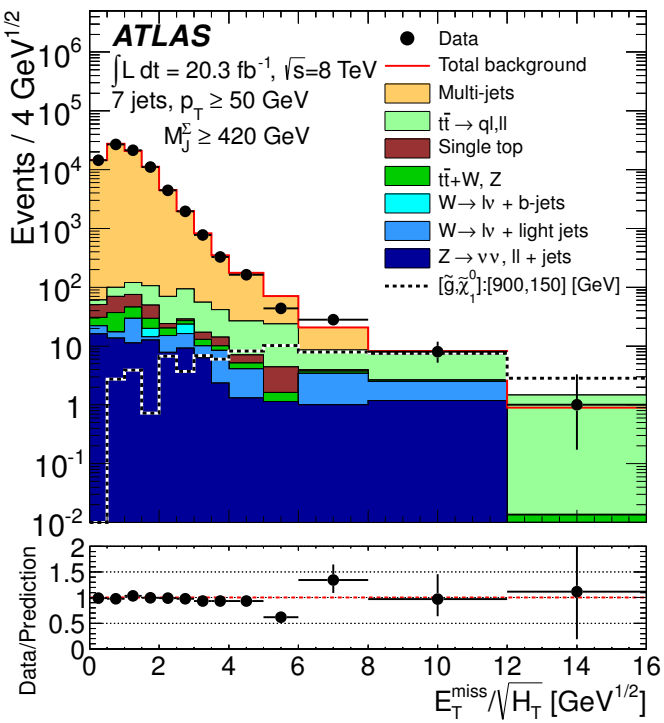
- Backgrounds:
  - Multijet backgrounds: QCD multijet, hadronic ttbar, W+jets, Z+jets
  - Leptonic backgrounds: leptonic decay of ttbar, W+jets and Z+jets

0lepton + 7 to 10 jets + MET: Background estimation

arXiv: 1308.1841

- Multi-jet background:
  - Use the shape of $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ with low jet multiplicity and normalize the shape using low $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} < 4$ GeV^{-2}
- Leptonic background: normalize MC predictions using CR dominated by background process undergoing estimation





Searches with leptons + jet and MET

- Require 1 or 2 leptons + jet and MET:
  - Targeting leptonic decays of charginos, neutralinos, sleptons, sneutrino either directly or through immediate steps.
  - The lepton can be soft for better sensitive to compress spectrum
- Channel includes:
  - 1 hard lepton + 3-6 jets
  - 1 or 2 soft leptons + 2-5 jets
  - 2 leptons + jets + MET: same sign, razor anlysis
- Major backgrounds:
  - QCD multijets
  - Ttbar, W+jets
  - Other backgrounds from diboson, single top, ttbar + V

1 hard lepton + 3-6 jets

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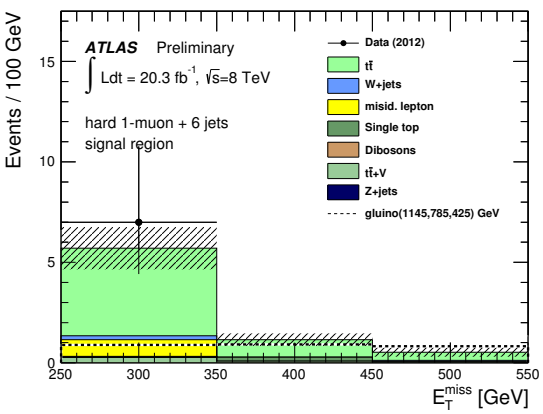
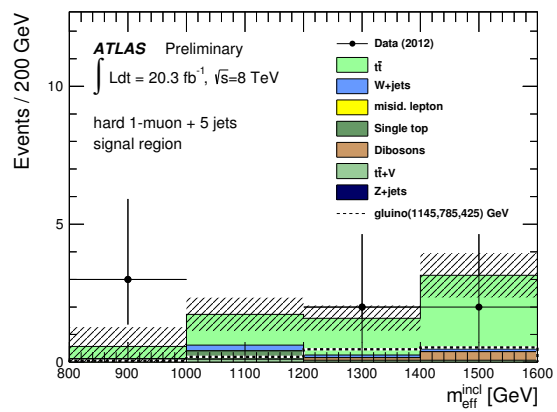
- Signal definitions

	inclusive (binned) hard single-lepton		
	3-jet	**5-jet**	**6-jet**
N_ℓ	1 (electron or muon)		
p_T^ℓ(GeV)	> 25		
$p_T^{\text{add. }\ell}$ (GeV)	< 10		
N_{jet}	≥ 3	≥ 5	≥ 6
p_T^{jet}(GeV)	> 80, 80, 30	> 80, 50, 40, 40, 40	> 80, 50, 40, 40, 40, 40
$p_T^{\text{add. jets}}$(GeV)	– (< 40)	– (< 40)	–
E_T^{miss} (GeV)	>500 (300)	>300	>350 (250)
m_T (GeV)	> 150	> 200 (150)	> 150
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{excl}}$	> 0.3	–	–
$m_{\text{eff}}^{\text{incl}}$ (GeV)	> 1400 (800)		> 600





Soft leptons + jets + MET

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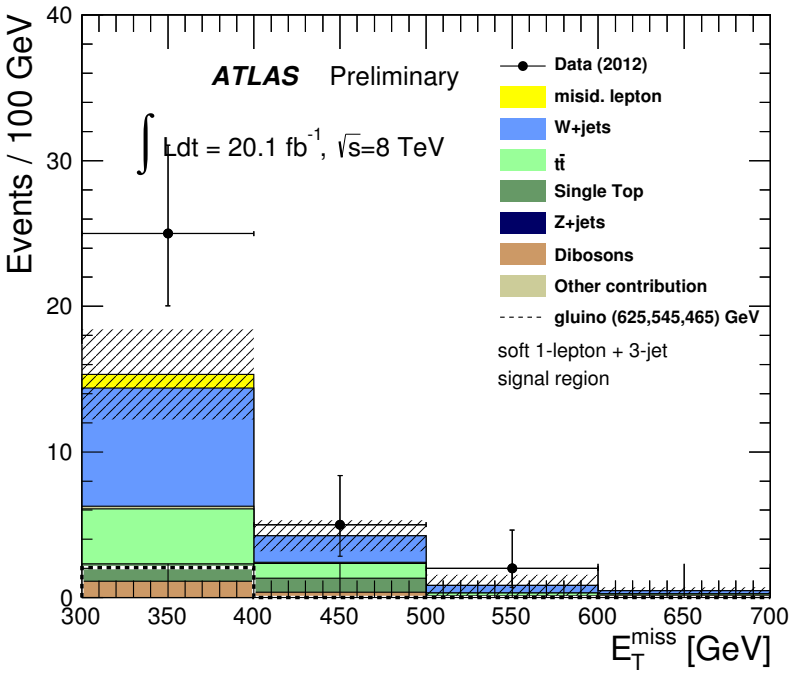
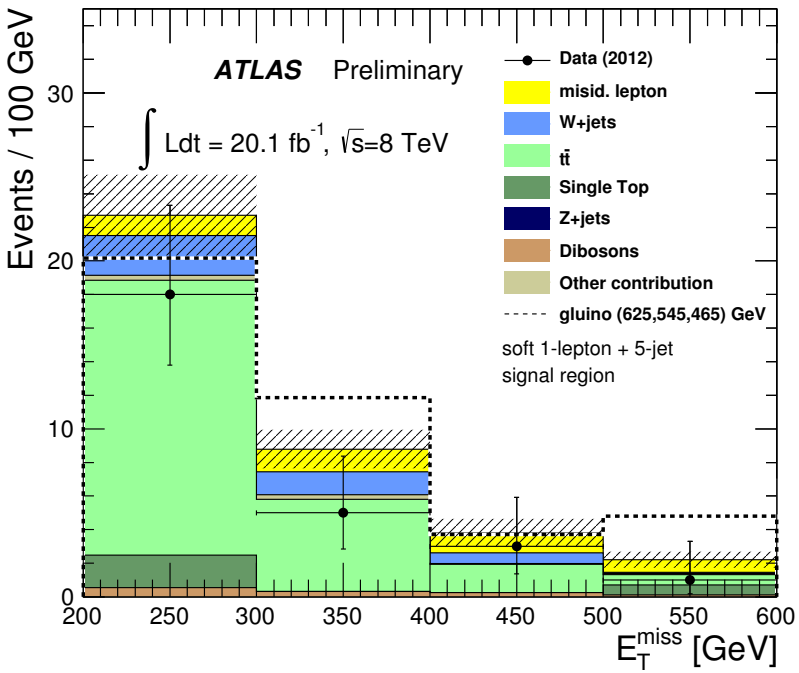
- Lepton pT < 25 GeV
- Signal regions includes:
  - 1 soft leptons + 3 to 4 jets -> short decay chain
  - 1 soft leptons + 5 jets -> long decay chain





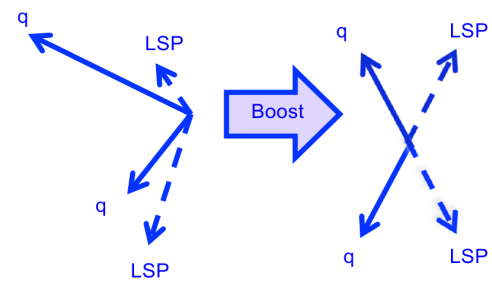
2leptons + jets + MET

- Razor variable utilize the symmetry of SUSY decay chain when s-particles produced in pairs

$$M'_R = \sqrt{(j_{1,E} + j_{2,E})^2 - (j_{1,L} + j_{2,L})^2},$$

$$R = \frac{M_T^R}{M'_R}.$$

$$M_T^R = \sqrt{\frac{|\vec{E}_{\mathrm{T}}^{\mathrm{miss}}|(|\vec{j}_{1,\mathrm{T}}| + |\vec{j}_{2,\mathrm{T}}|) - \vec{E}_{\mathrm{T}}^{\mathrm{miss}} \cdot (\vec{j}_{1,\mathrm{T}} + \vec{j}_{2,\mathrm{T}})}{2}}.$$



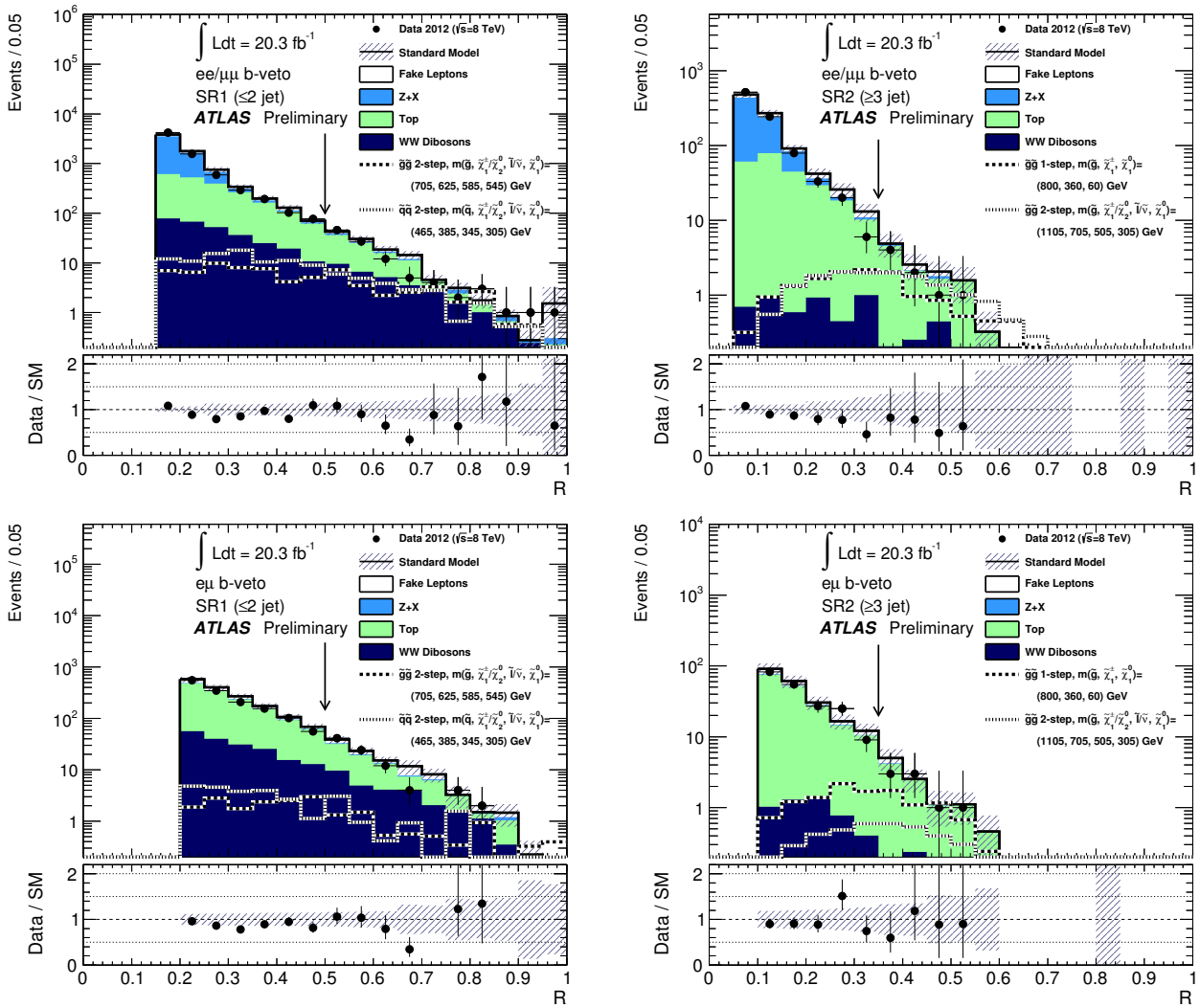
- R is low for SM backgrounds
- Signal definition

	b-jets	Z-veto	N_{Jets}	Jet p_{T}	R Range	M'_R Range [GeV]	M'_R bins
Signal Regions							
$ee/\mu\mu$ SR 1	No	Yes	≤ 2	> 50	R >0.5	400< M'_R	8
$e\mu$ SR 1	No	No	≤ 2	> 50	R >0.5	400< M'_R	8
$ee/\mu\mu$ SR 2	No	Yes	≥ 3	> 50	R >0.35	800< M'_R	5
$e\mu$ SR 2	No	No	≥ 3	> 50	R >0.35	800< M'_R	5
Discovery Regions							
$ee/\mu\mu$ DR	No	Yes	≤ 2	> 50	R >0.5	600< M'_R	1
$e\mu$ DR	No	No	≤ 2	> 50	R >0.5	600< M'_R	1

2 leptons + jets + MET

ATLAS-CONF-2013-089

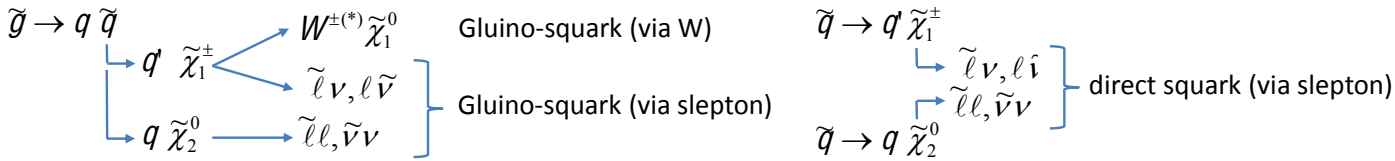
- Razor distribution after final selection



2 same-sign lepton

ATLAS-CONF-2013-007

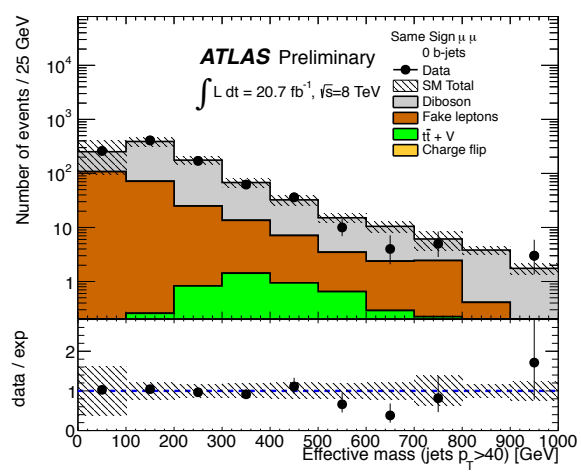
- Model:

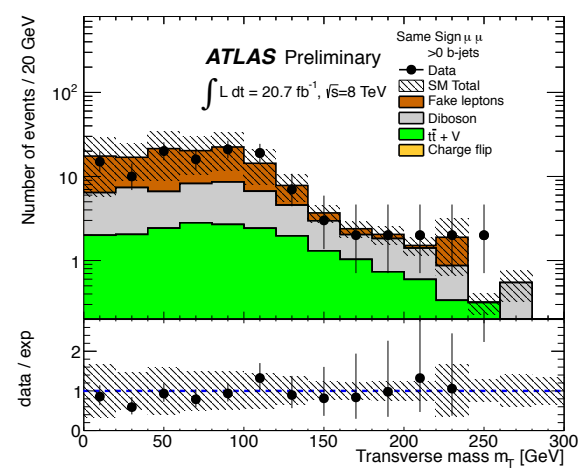


- Signal regions:

Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV,
		$m_T > 100$ GeV, $m_{eff} > 400$ GeV	binned shape fit in m_{eff} for $m_{eff} > 300$ GeV

- Backgrounds:
  - ttbar, diboson
  - charge misidentification: use charge flip probability identified from Drell-Yan process

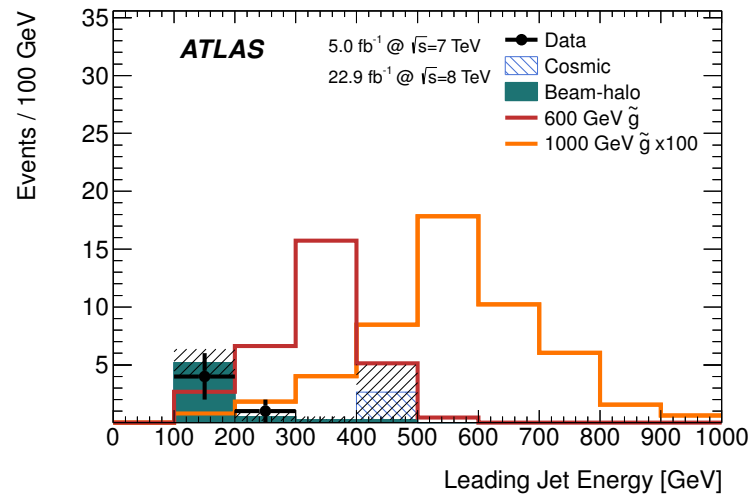


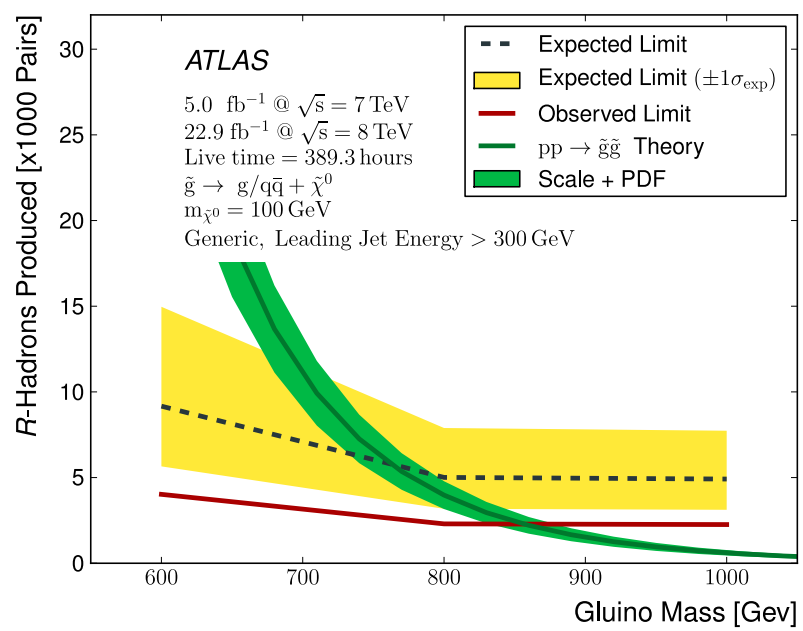


R-hadron search

- Gluino, squark are hadronized into R-hadron: $\tilde{g}q\bar{q}$, $\tilde{g}qqq$, $\tilde{g}g$, $\tilde{t}\bar{q}$.
- Some R-hadrons loose their momentum, stop in the calorimeter and decay to neutralino and jets at later time -> candidate events selected empty bunch crossing
- Selection: at least one high energy jet and no muon segments in the muon system
  - Jet: |η| < 1.2, pT > 50 GeV, up to five jets are allowed
  - No muon segment with more than 4 hits
  - Two signal region with leading jet pT > 100 and 300 GeV
- Backgrounds: beam halos and cosmic rays

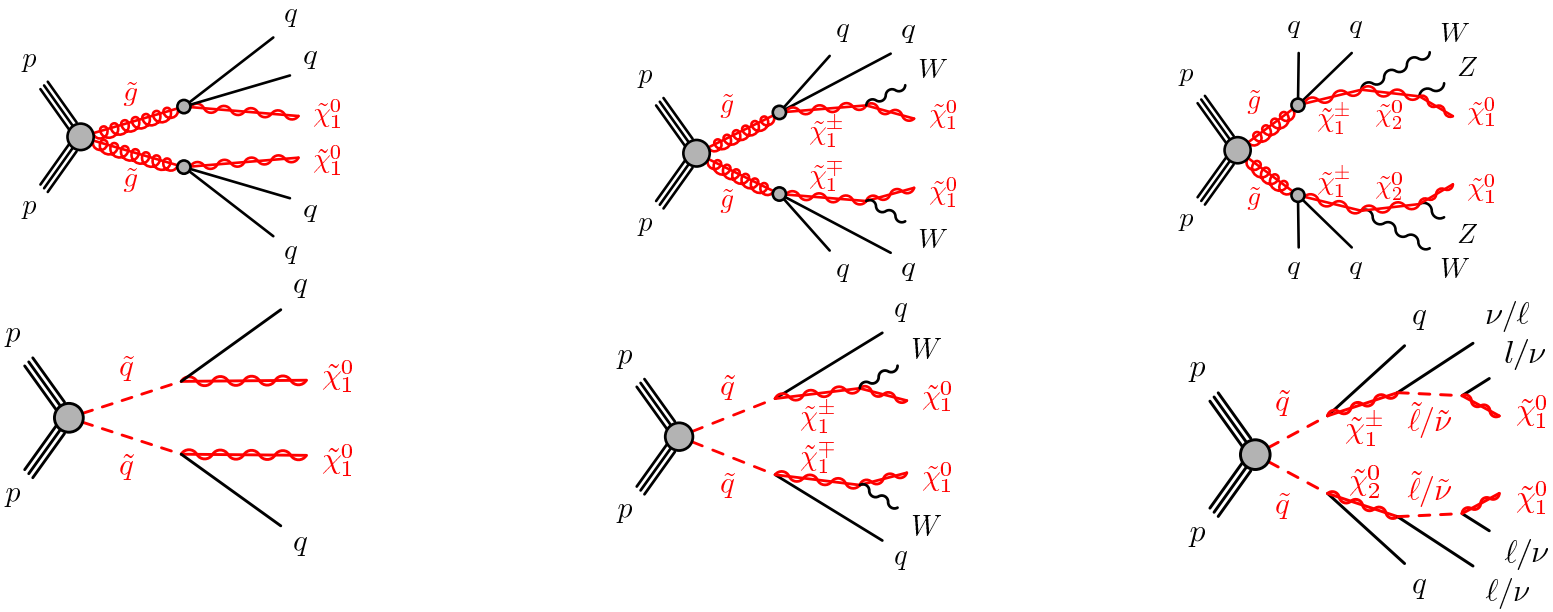
arXiv: 1310.6584





Interpretations of search results

- Simplified models:
  - Direct decays of gluinos and squarks to jets
  - 1-step decays of gluinos and squarks via chargino
  - 2-step decays of gluinos and squarks



- mSUGRA/cMSSM

Simplified model: direct decay of gluino and squark to jets and LSP

- 0-lepton analysis

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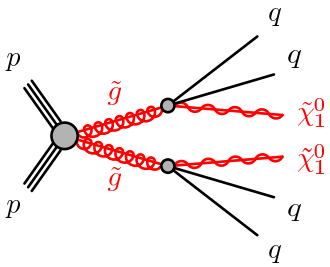
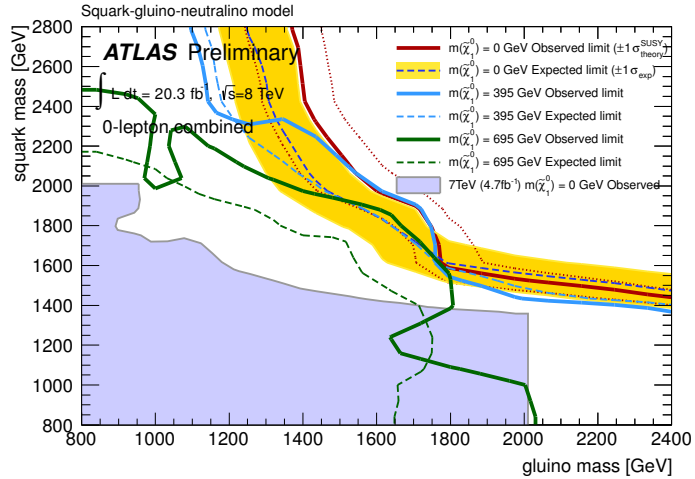
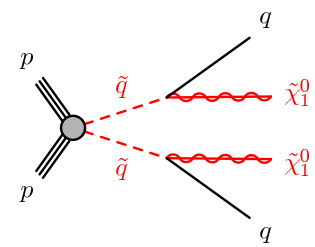
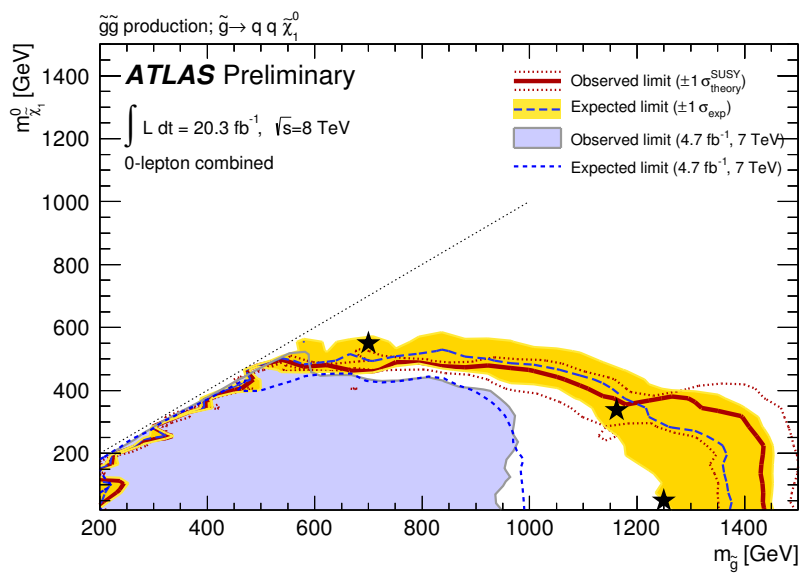
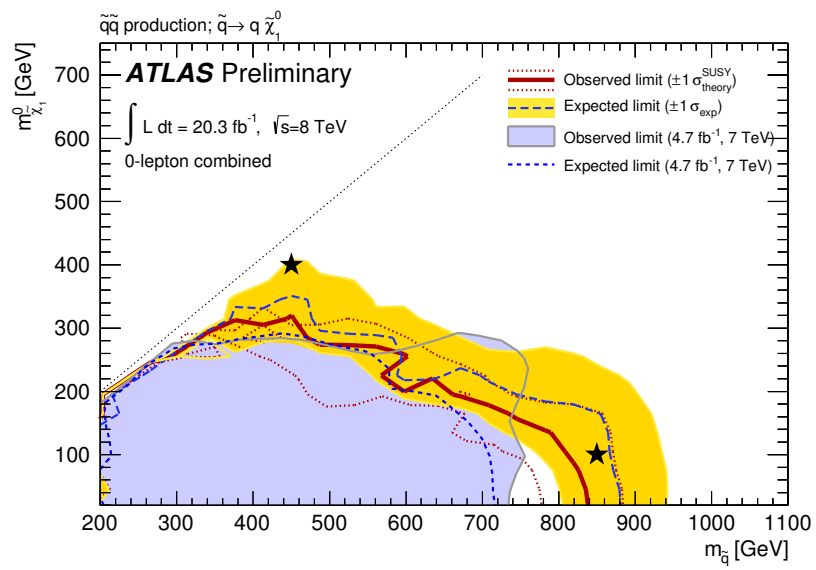


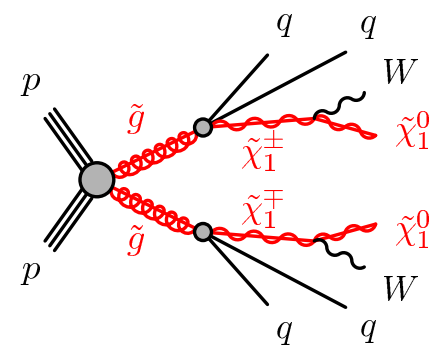




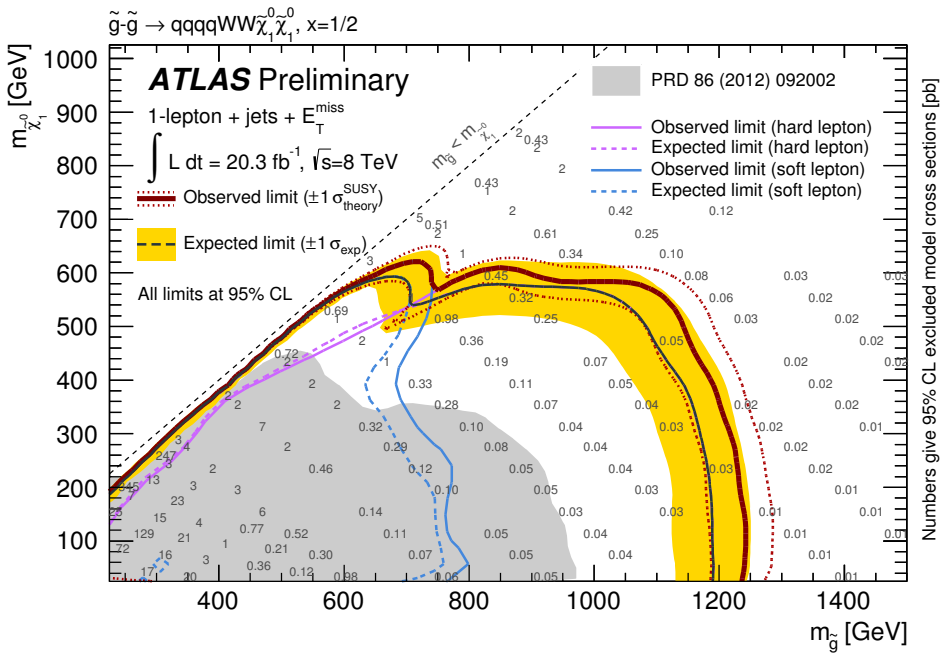




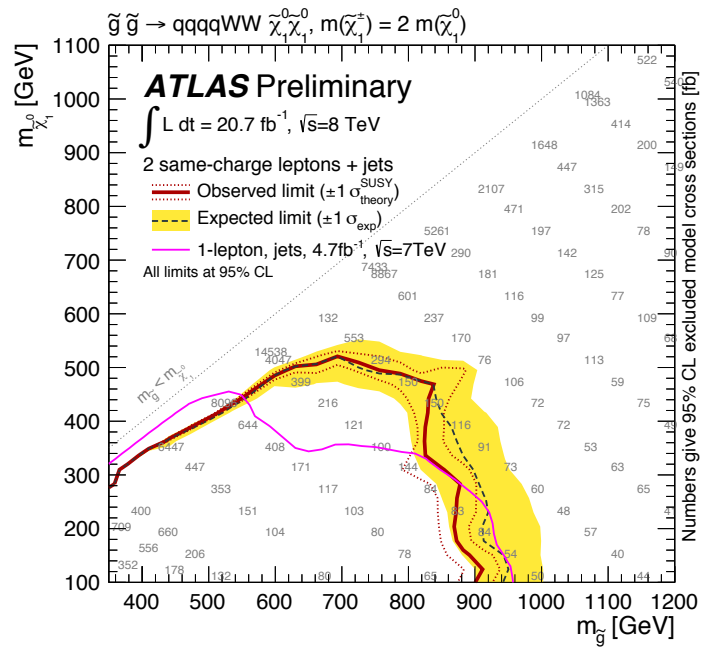
Simplified model: 1-step gluino and squark decay to jets, W and LSP through chargino



Gluino mass limits



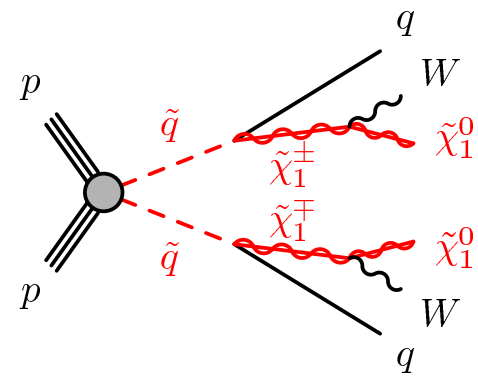
1lepton + jets (ATLAS-CONF-2013-062)

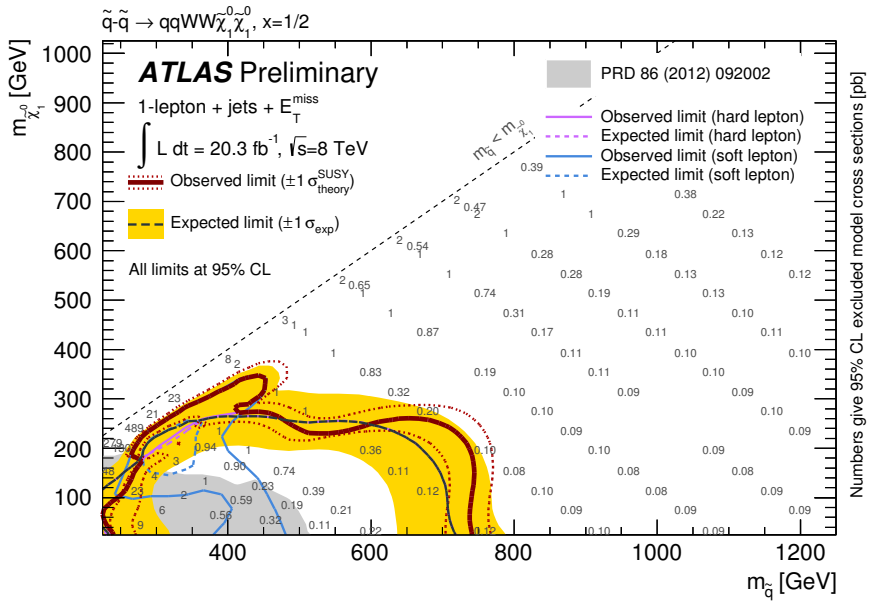


2 same-sign lepton (ATLAS-CONF-2013-007)

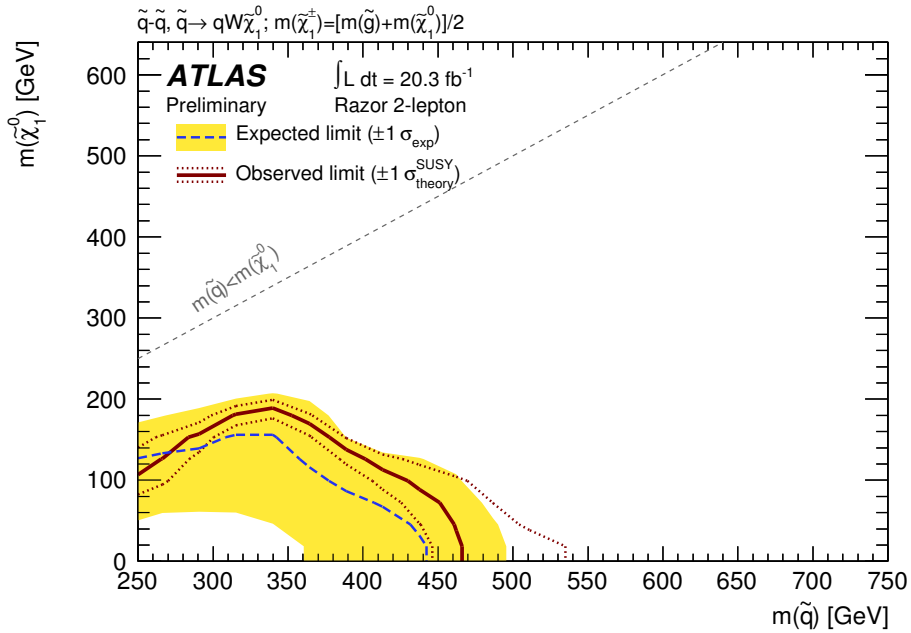
Simplified model: 1-step gluino and squark decay to jets, W and LSP through chargino

- Squark mass limits





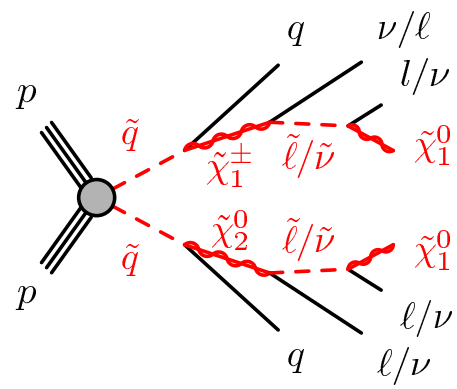
1lepton+jets (ATLAS-CONF-2013-062)

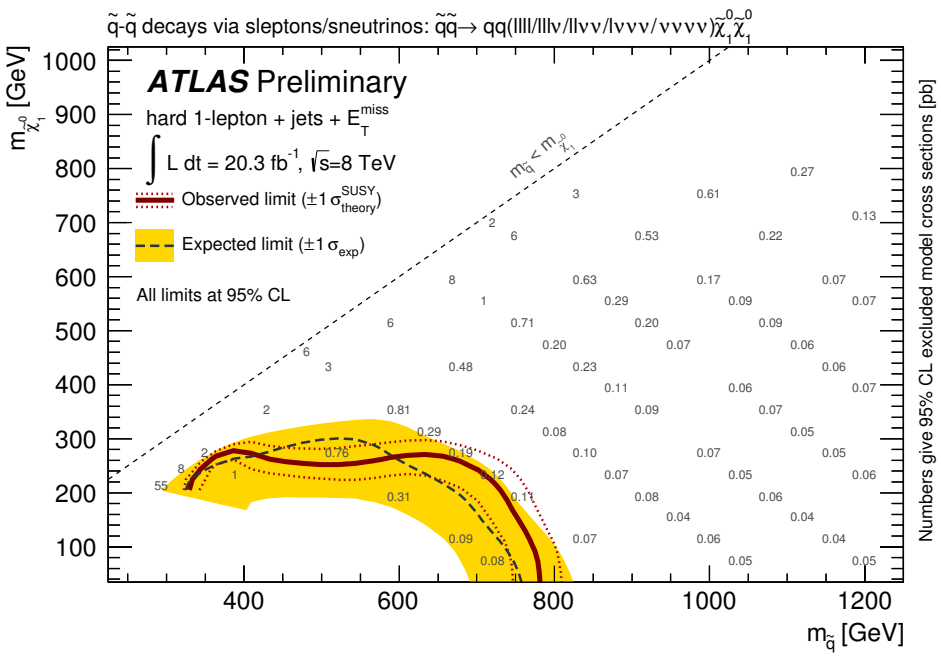


2lepton+jets (ATLAS-CONF-2013-089)

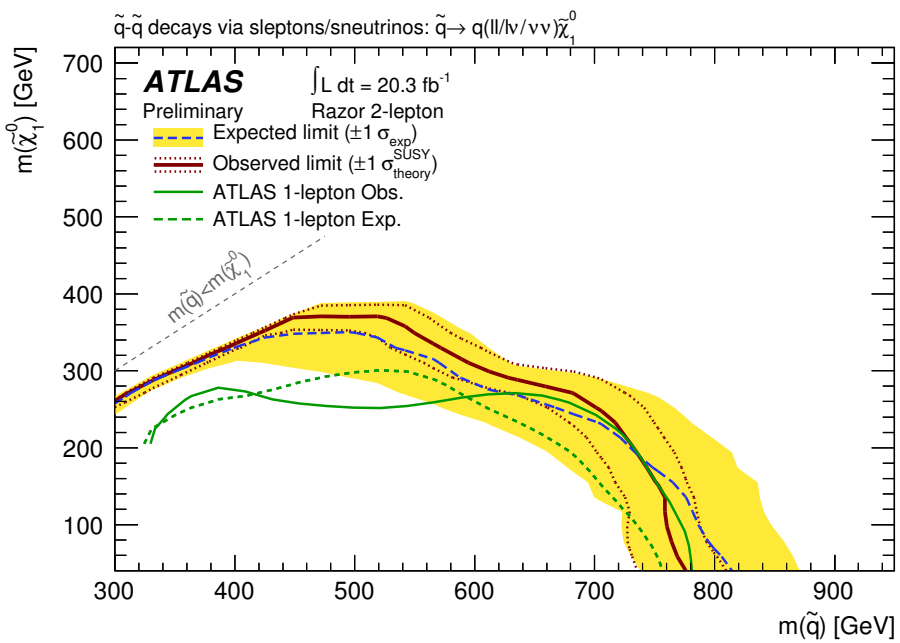
Simplified model: 2-step gluino and squark decay

- Squark mass limit





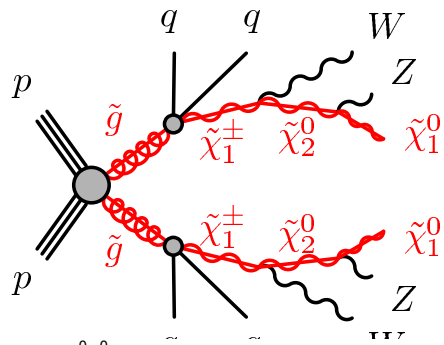
1lepton+jets (ATLAS-CONF-2013-062)

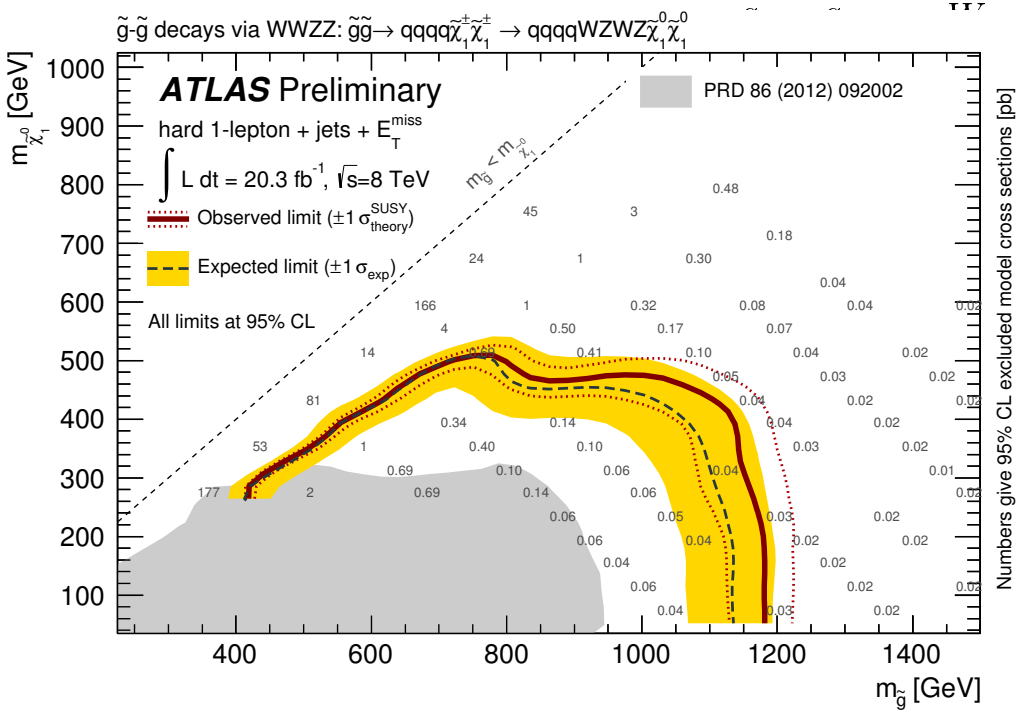


2lepton+jets (ATLAS-CONF-2013-089)

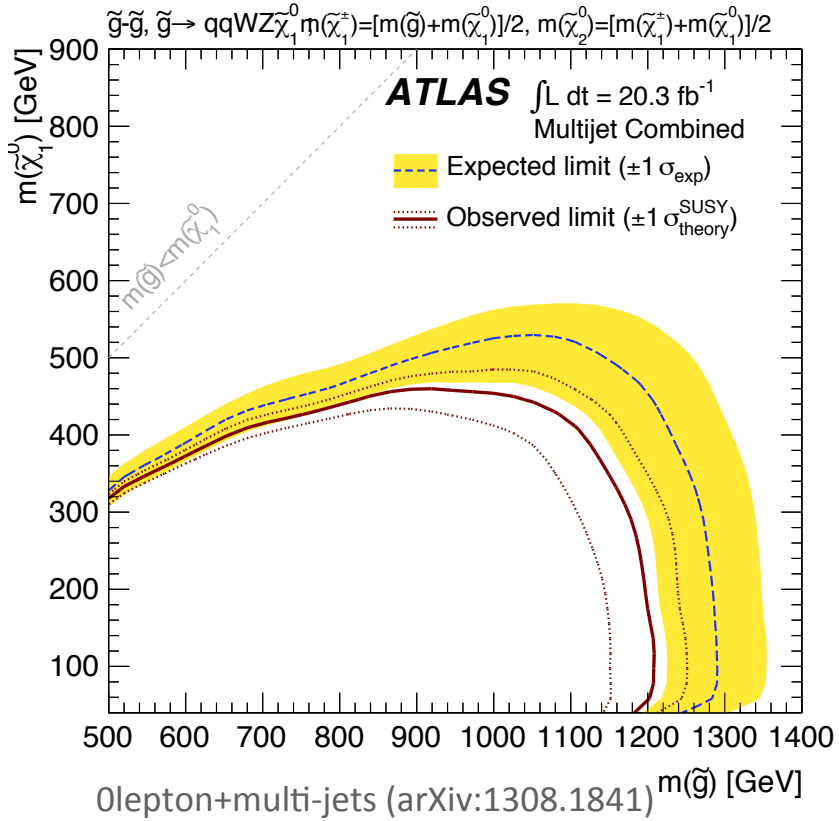
Simplified model: 2-step gluino and squark decay

- Gluino mass



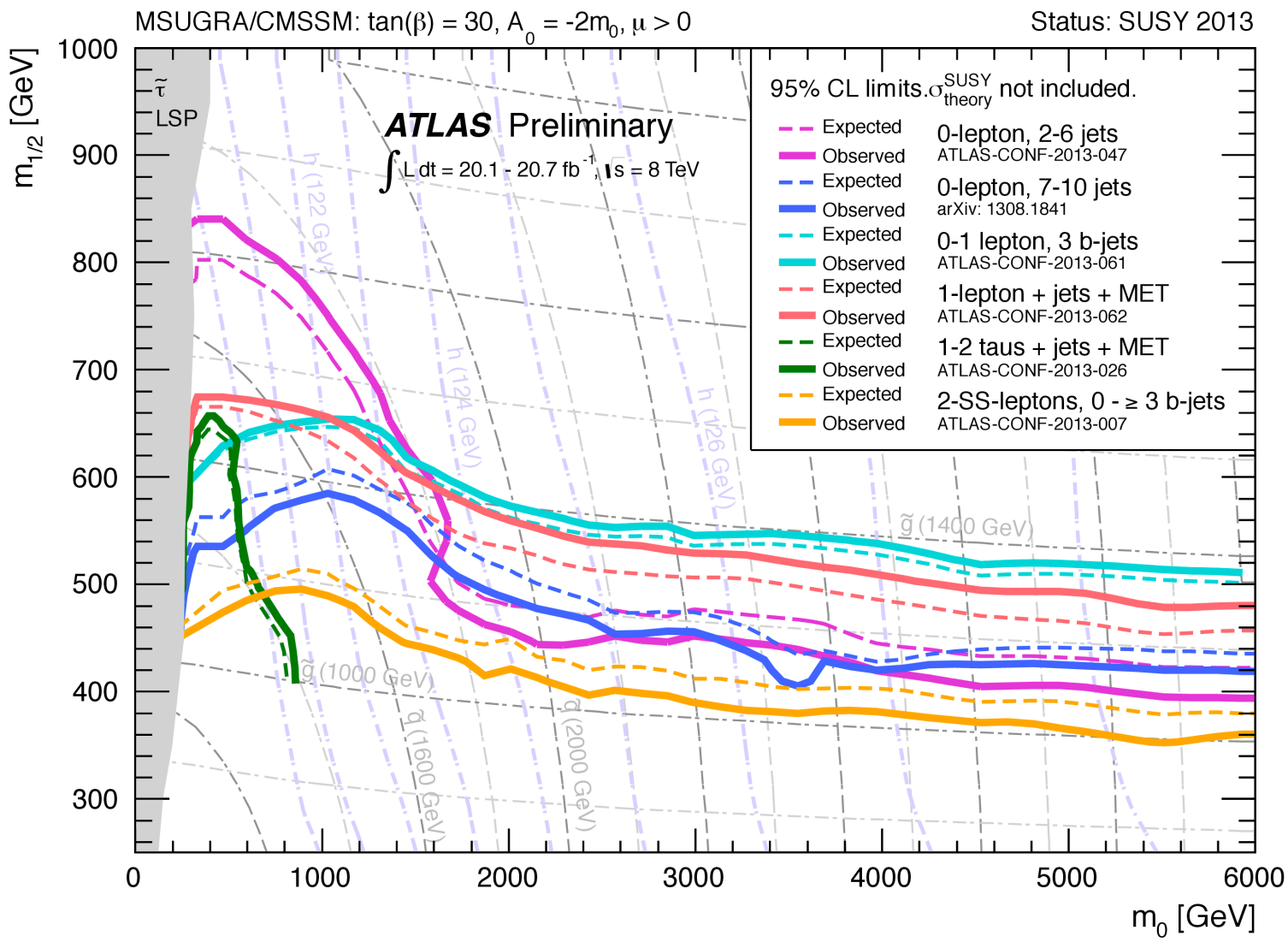


1lepton+jets (ATLAS-CONF-2013-062)



0lepton+multi-jets (arXiv:1308.1841)

mSUGRA/cMSSM



Summary

- No sign of SUSY found in inclusive search with jets and missing transverse energy
- Efficient search techniques have been developed which can be recycled for new runs
- Stringent limits on gluino, squarks, lightest neutralino masses
  - Gluino and squark mass > 1 TeV
- 14 TeV runs promise exciting new results