Inclusive searches for supersymmetric signatures with the ATLAS detector

Devin Harper, U. of Michigan

on behalf of the ATLAS collaboration

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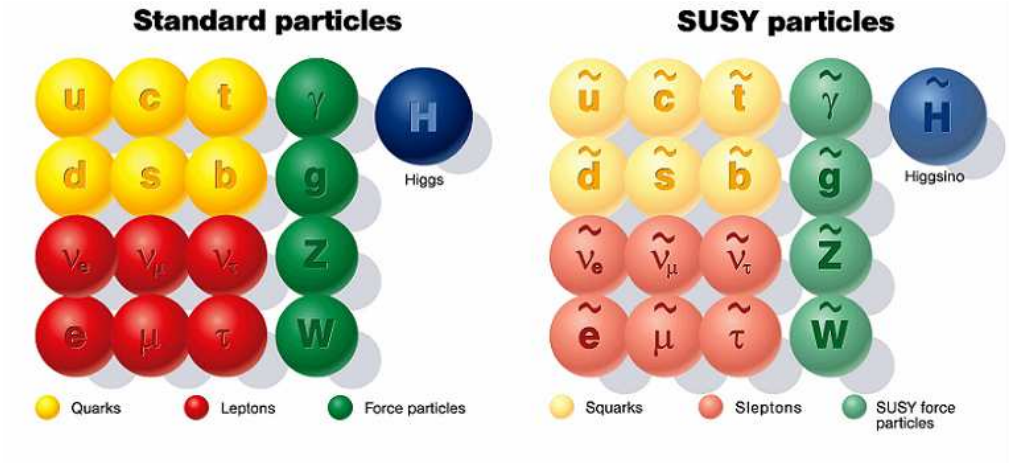
Weak scale supersymmetry (SUSY) introduces a new symmetry between fermions & bosons:

$$Q|\text{Fermion}\rangle = |\text{Boson}\rangle, \quad Q|\text{Boson}\rangle = |\text{Fermion}\rangle$$



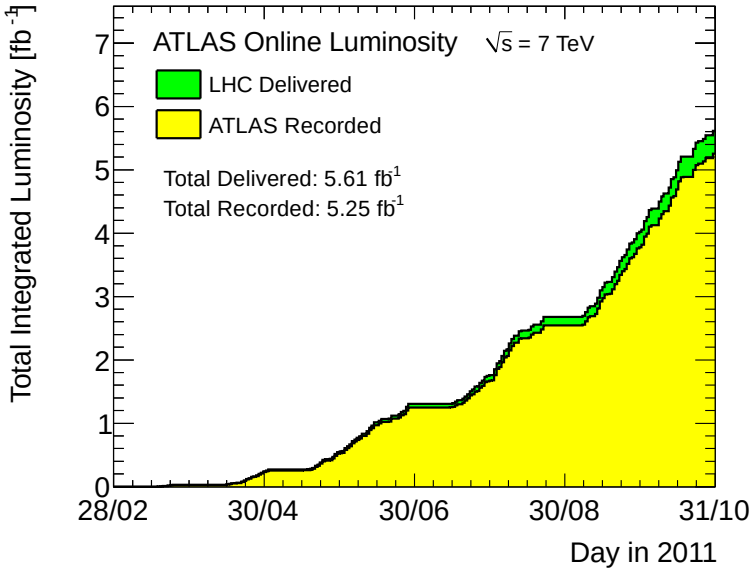
Striking features:

(1) Provides new fields which help with cancellation of large divergences in Δm_H^2

(2) Assuming R-parity conservation:
- Sparticles produced in pairs
- Gives rise to the stable **LSP** – the lightest supersymmetric particle, which can be a candidate for dark matter

(3) Provides unification of gauge couplings

No observation of SUSY particles $\longrightarrow$ *SUSY is a broken symmetry!*

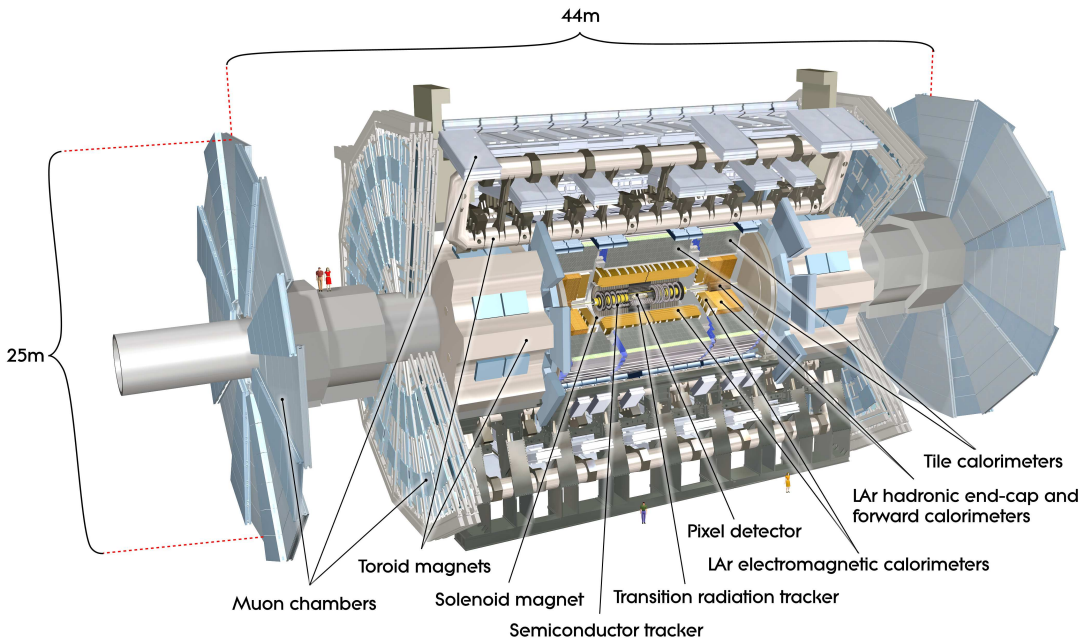


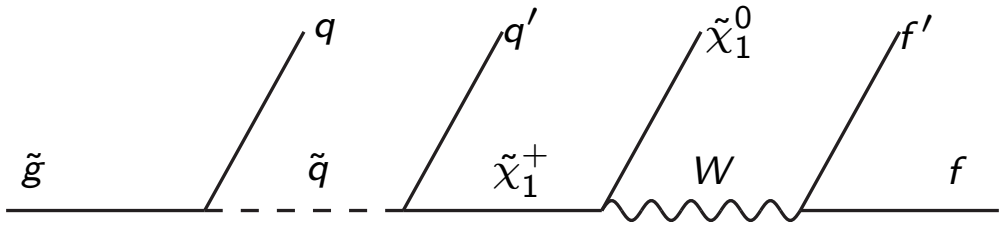
LHC

- 2011: a very successful pp collision program!
- $\sqrt{s} = 7$ TeV
- Peak luminosity: 3.65×10^{33} cm^{-2} s^{-1}
- Total 2011 deliverered luminosity: 5.615 fb^{-1}
- Up from 2010 luminosity of 35 pb^{-1}

ATLAS

- Precision tracking
- Calorimetry
- Muon system
- 3-level trigger
- 93.5% data-taking efficiency





- Define signal region(s) (SR) with quantities that help discriminate against SM backgrounds, features of $\tilde{q}$, $\tilde{g}$ cascade decays:
  - E_T^{miss}(assuming R-parity conservation, the LSP escapes detection)
  - jet multiplicity
  - Transverse mass
  - Scalar p_T sum of objects: $H_T \equiv \sum_i p_T^{\text{jet},i} + \sum_i p_T^{\text{lepton},i} + \sum_i p_T^{\text{photon},i}$
  - Effective mass: $m_{\text{eff}} = H_T + E_T^{\text{miss}}$
  - Other hard objects (leptons, photons, ...)
- Background determination
  - Fake and multijet backgrounds estimated from data-driven methods
  - Dominant electroweak and top backgrounds estimated from data using control regions, transferred to the signal region using MC simulation:

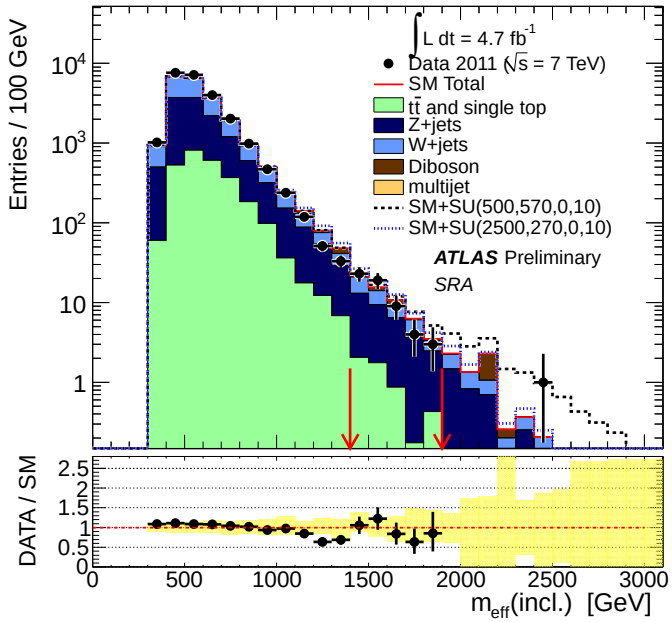
$$N_{\text{est, SR}} = \frac{N_{\text{MC, SR}}}{N_{\text{MC, CR}}} \times (N_{\text{obs, CR}} - N_{\text{bkg, CR}})$$

  - Similar electroweak backgrounds estimated from MC simulation
- In general not searching for mass peaks, but instead watching for excesses in tails of distributions

Search with the $\geq 2-6$ jets + E_T^{miss} final state

performed with 4.7 fb^{-1}

- ATLAS-CONF-2012-033
- Targets squark and gluino production
  - $\tilde{q}$, $\tilde{g}$ decays: jets, LSP
- Selection:
  - Veto events with good leptons
  - Require $\geq 2-6$ jets
  - Use azimuthal separation between jets & E_T^{miss} to remove QCD multijet background
  - Use m_{eff} and E_T^{miss} to define SRs
- Backgrounds: $W+\text{jets}$, $Z+\text{jets}$, $t\bar{t}$



m_{eff} after 2-jet SR selection

(without m_{eff} cut)

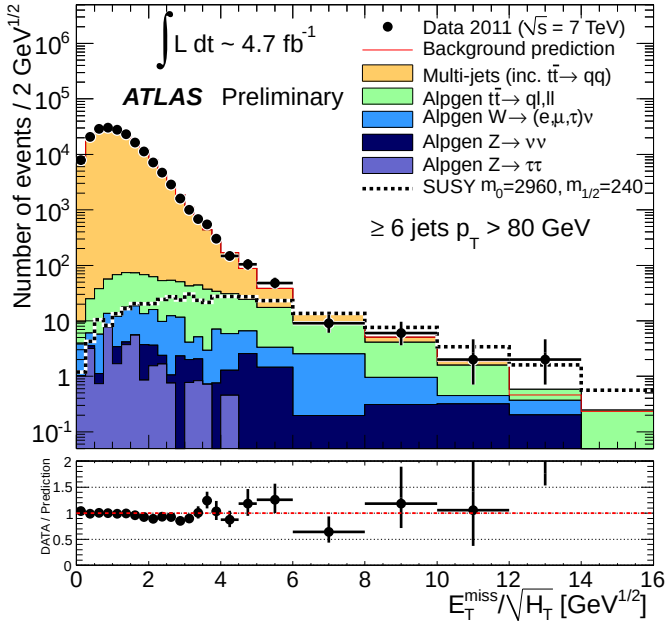
Signal region definitions:

Requirement	Channel					
	2 jet	2 jet (soft)	3 jet	4 jet	5 jet	6 jet
E_T^{miss} [GeV]$>$	160					
$\Delta\phi(\text{jet}, E_T^{\text{miss}})_{\text{min}} >$	$0.4(i=1,2,(3))$			$0.4(i=1,2,(3))$,$0.2(p_T > 40$ GeV jets)		
$E_T^{\text{miss}}/m_{\text{eff}}(Nj) >$	0.3(2j)	0.4(2j)	0.25(3j)	0.25(4j)	0.2(5j)	0.15(6j)
m_{eff}(incl.) [GeV] $>$	1900/1400/–	–/1200/–	1900/–/–	1500/1200/900	1500/–/–	1400/1200/900

Search with the $\geq 6-9$ jets + E_T^{miss} final state

performed with 4.7 fb^{-1}

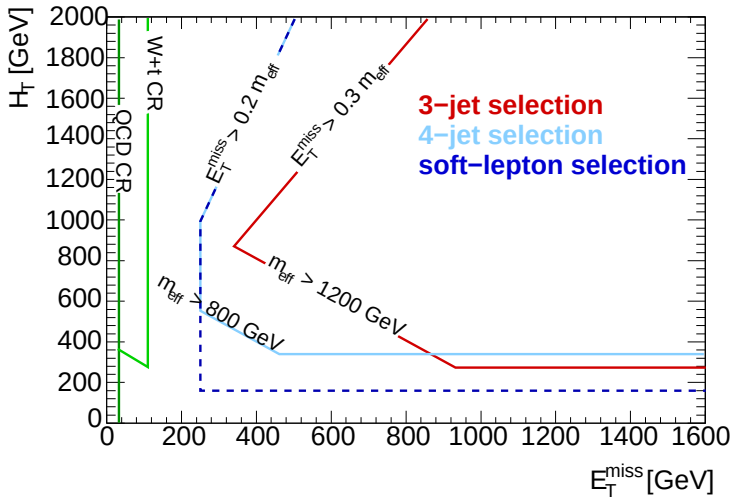
- ATLAS-CONF-2012-037
- Utilizes large jet multiplicity from $\tilde{g}$ decays
- Selection:
  - Veto events with good leptons
  - Require $\geq 6-9$ jets
  - Use E_T^{miss} significance ($E_T^{\text{miss}}/\sqrt{H_T}$) to define SRs
- Backgrounds: $W+$jets, $Z+$jets , $t\bar{t}$, multijet
  - Dominant multijet (including hadronic $t\bar{t}$) background taken from data



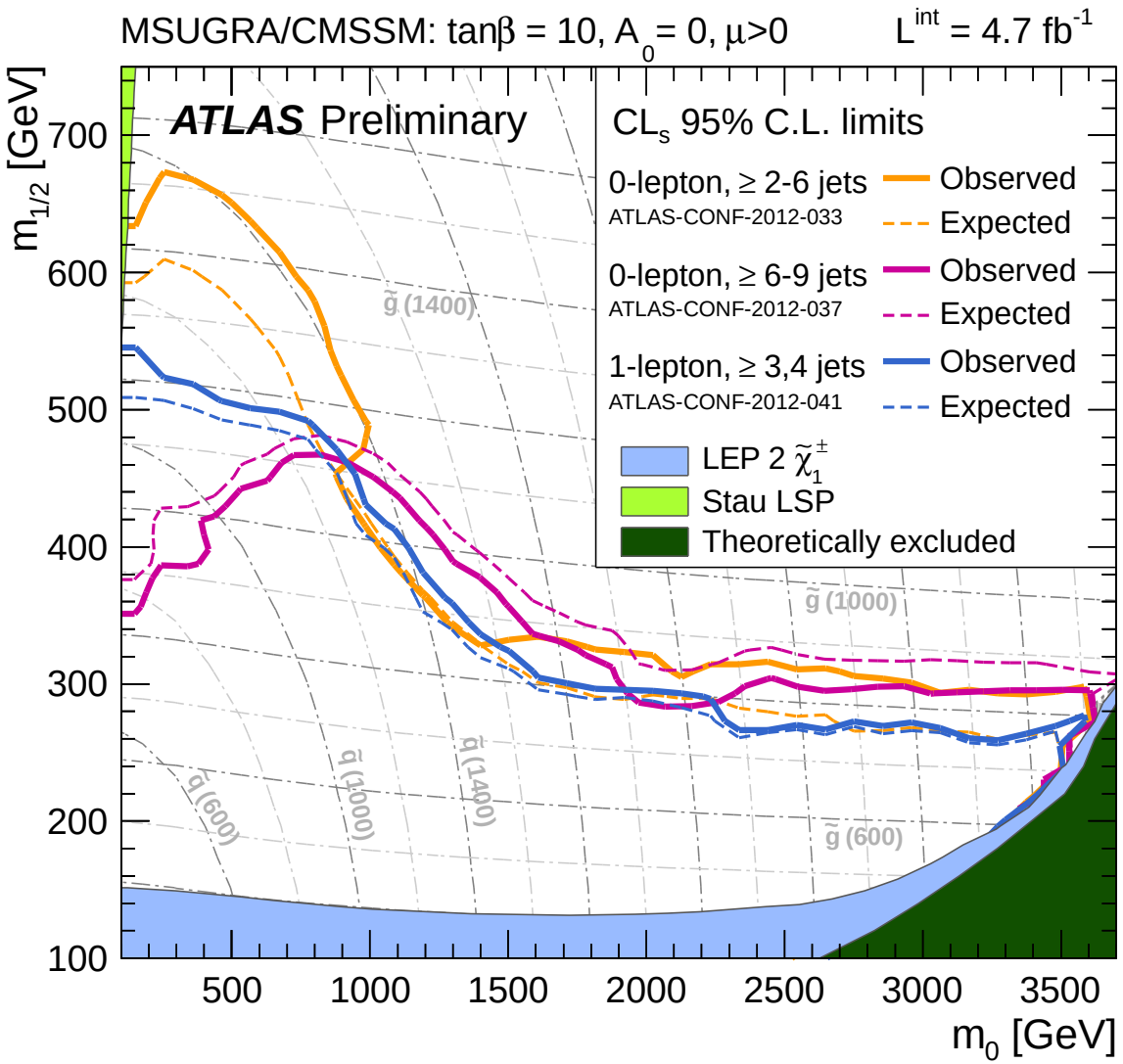
E_T^{miss} significance in 6-jet SR

Requirement	Channel					
	7 jet	8 jet	9 jet	6 jet	7 jet	8 jet
Jet p_T	> 55 GeV			> 80 GeV		
Jet $\lvert\eta\rvert$	< 2.8					
Number of jets	≥ 7	≥ 8	≥ 9	≥ 6	≥ 7	≥ 8
$E_T^{\text{miss}}/\sqrt{H_T}$	> 4 GeV$^{1/2}$					
SM	167±34	17±7	1.9±0.8	107±21	8.6±2.5	0.80±0.45
Data	154	22	3	106	15	1

- ATLAS-CONF-2012-041
- Utilize a hard lepton from SUSY cascade
  - Clean signature, good identification
  - Reduce QCD multijet background
  - Trigger
- Selection:
  - Require exactly 1 lepton
  - Use E_T^{miss}, m_T, and m_{eff} for SRs



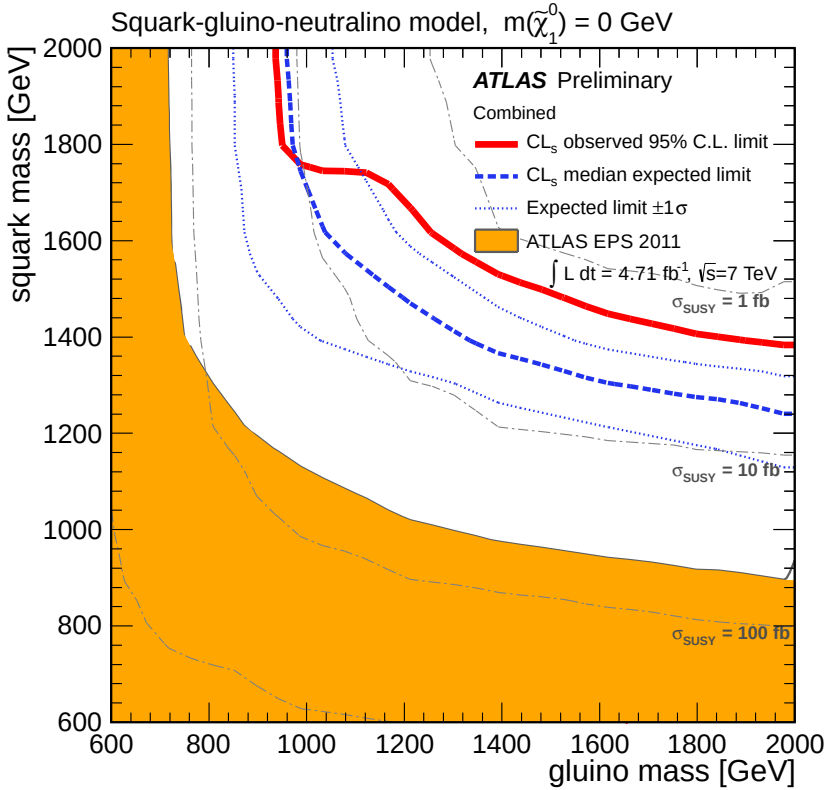
Requirement	Channel		
	3 jet	4 jet	soft-lepton
p_{T}^{ℓ} (GeV)	$>$ 25 (20)	$>$ 25 (20)	[7,25] ([6,20])
N_{jet}	$\geq$ 3	$\geq$ 4	$\geq$ 2
p_{T}^{jet} (GeV)	$>$ 100, 25, 25	$>$ 80, 80, 80, 80	$>$ 130,25
E_T^{miss} (GeV)	$>$ 250	$>$ 250	$>$ 250
m_{T} (GeV)	$>$ 100	$>$ 100	$>$ 100
$E_T^{\text{miss}}/m_{\text{eff}}$	$>$ 0.3	$>$ 0.2	$>$ 0.3
$m_{\text{eff}}^{\text{inc}}$ (GeV)	$>$ 1200	$>$ 800	—
SM	5.7$\pm$4.0	8.3$\pm$3.1	32$\pm$11
Observed	3	6	26



Squark and gluino masses below 1.4 TeV excluded!

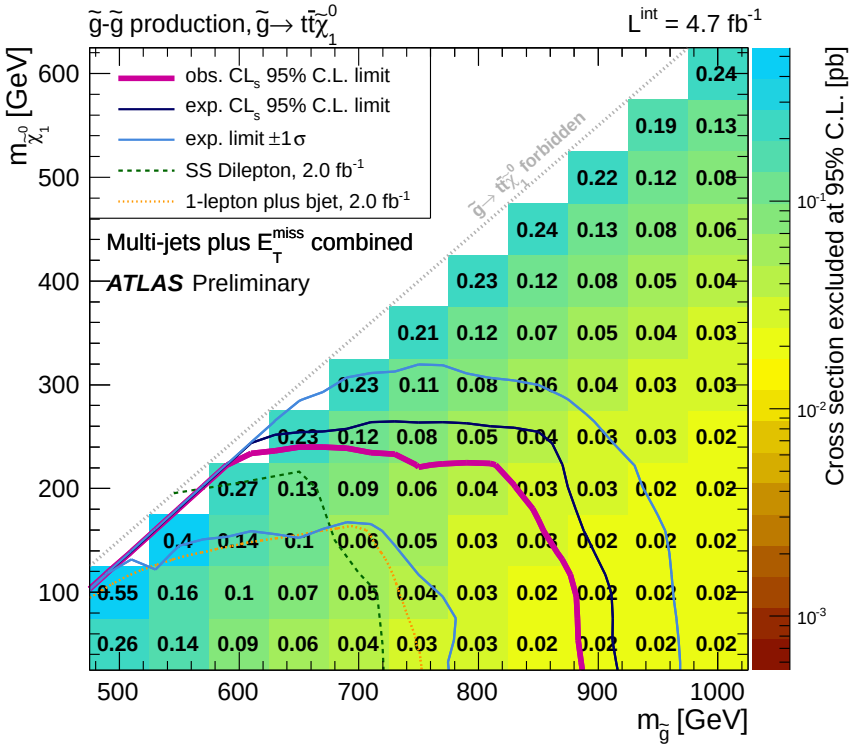
(left) **Phenomenological models** with $m(\tilde{\chi}_1^0) = 0$, and all other masses (except $m(\tilde{q})$ and $m(\tilde{g})$) set to 5 TeV. Used to interpret $\geq 2-6$ jets analysis results.

(right) **Simplified models** with gluino pair production, and gluinos decaying to $t\bar{t}\tilde{\chi}_1^0$ with probability 1. Used to interpret results from $\geq 6-9$ jets analysis.



1.38 TeV limit on $\tilde{q}$ mass ($m(\tilde{g}) < 2$ TeV, light $\tilde{\chi}_1^0$)

940 GeV limit on $\tilde{g}$ mass ($m(\tilde{q}) < 2$ TeV, light $\tilde{\chi}_1^0$)



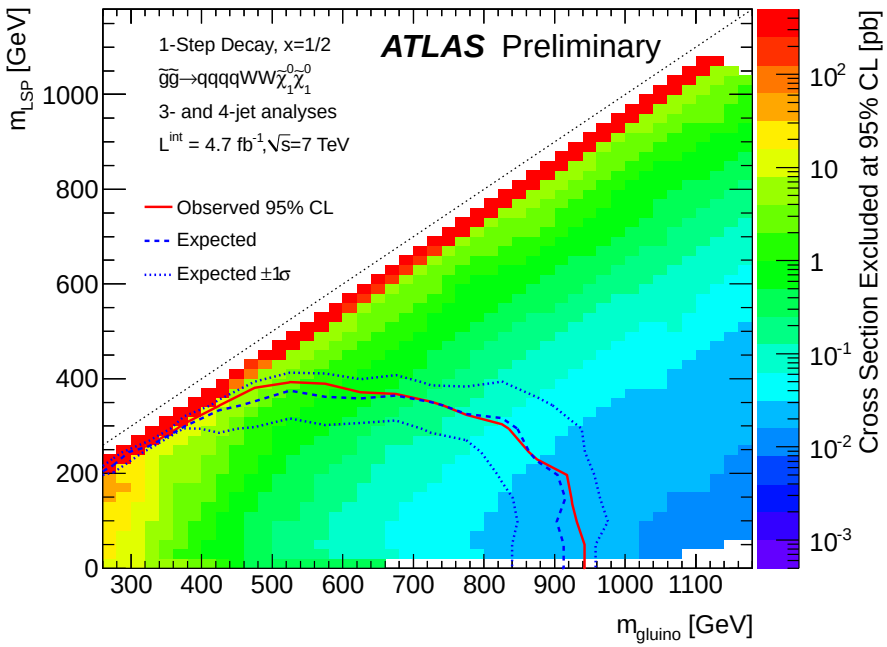
830 GeV limit on $\tilde{g}$ mass ($m(\tilde{\chi}_1^0) < 200$ GeV)

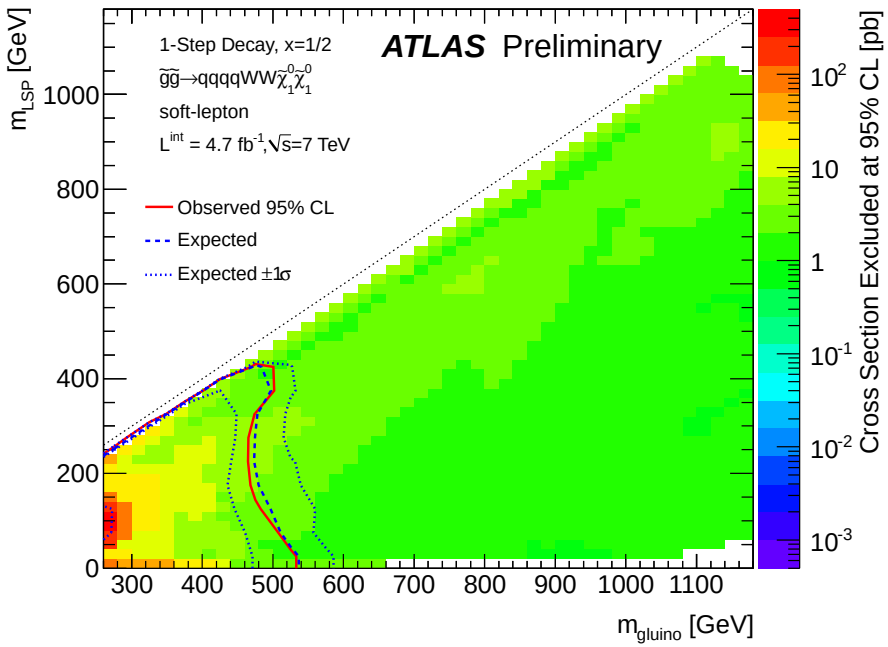
Interpretation with **simplified models**:

$\tilde{g}\tilde{g}$ pair production, followed by $\tilde{g} \to q\overline{q}'\,\tilde{\chi}_1^{\pm} \to q\overline{q}'\,W^{\pm}\tilde{\chi}_1^0$

(left) 3- and 4-jet analyses extend exclusion limits to high $m(\tilde{g})$ and $m(\tilde{\chi}_1^0)$

(right) soft-lepton analysis adds sensitivity for models with small mass differences in decay chain





900 GeV limit on $\tilde{g}$ mass ($m(\tilde{\chi}_1^0) < 200$ GeV, $m(\tilde{\chi}^{\pm}) = \frac{1}{2}(m(\tilde{\chi}^0) + m(\tilde{g}))$

Limits on visible cross section: 1.5 fb (3.7 fb) for the 3/4-jets (soft-lepton) analysis

- In GMSB models, LSP is the gravitino ($\widetilde{G}$)
- The next-to-lightest SUSY particle (NLSP) determines phenomenology
- Possible NLSPs: $\tilde{\tau}$, $\tilde{\chi}_1^0$, $\tilde{\ell}$, $\tilde{g}$
  - $\tilde{\tau}$ NLSP: final states with τ leptons
  - $\tilde{\chi}_1^0$ or $\tilde{\ell}$ NLSP: final states with leptons

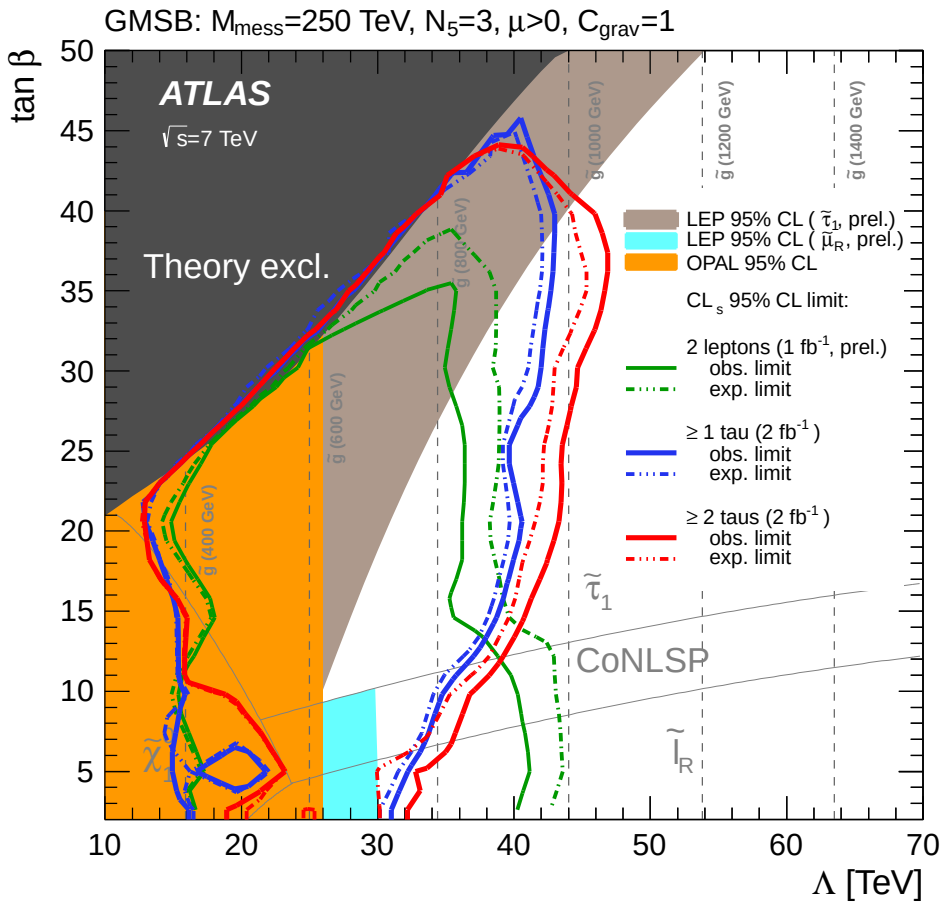
$\tilde{\tau}$ analyses

- Performed on 2 fb^{-1}
- SRs based on jets, E_T^{miss}, m_{eff}, and $m_T(\tau, E_T^{\text{miss}})$
- Backgrounds: Top, W, Z
- 1τ search: arXiv:1204.3852
- 2τ search: arXiv:1203.6580
- Both submitted to PLB

	1τ channel	2τ channel
Obs.	11	3
SM Bkg.	13.2±4.2	5.3±2.6
UL on σ_{vis}	4.0 fb	2.9 fb

Dilepton analysis

- ATLAS-CONF-2011-156
- Performed on 1 fb^{-1}
- SRs based on jets, E_T^{miss}
- Backgrounds: Top, dibosons



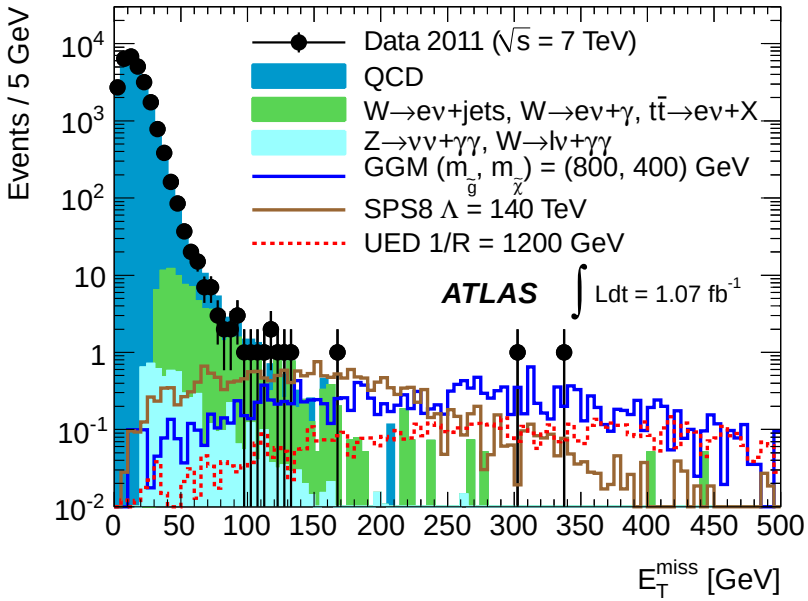
990 GeV limit on $\tilde{g}$ mass for $\tan\beta > 20$

Other GMSB: $\gamma\gamma + E_T^{\text{miss}}$ analysis

performed with 1.07 fb^{-1}

- Phys. Lett. B 710 (2012) 519-537 (link)
- If the NLSP is a bino-like neutralino, then we have $\tilde{\chi}_1^0 \to \gamma \widetilde{G}$
- Selection: diphoton requirement & $E_T^{\text{miss}} > 125$ GeV
- Major backgrounds: QCD (multijet, $\gamma +$ jets, $\gamma\gamma +$ jets), $W + X$, $t\bar{t}$

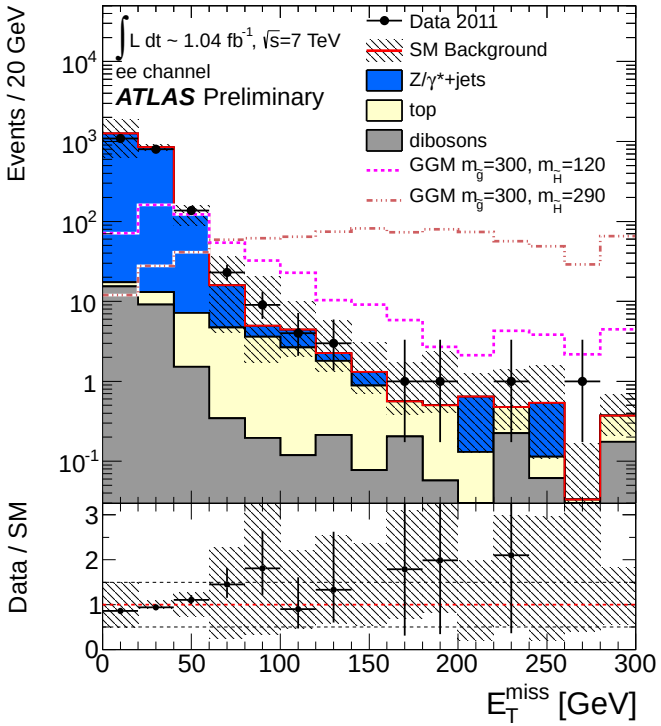
Background	$E_T^{\text{miss}} > 125$ GeV
QCD	0.8 ± 0.3
$W/t\bar{t}(\to e\nu) + X$	3.1 ± 0.5
Irreducible	0.23 ± 0.05
Total	4.1 ± 0.6
Observed	5



E_T^{miss} after diphoton selection.

First ATLAS SUSY search in this final state!

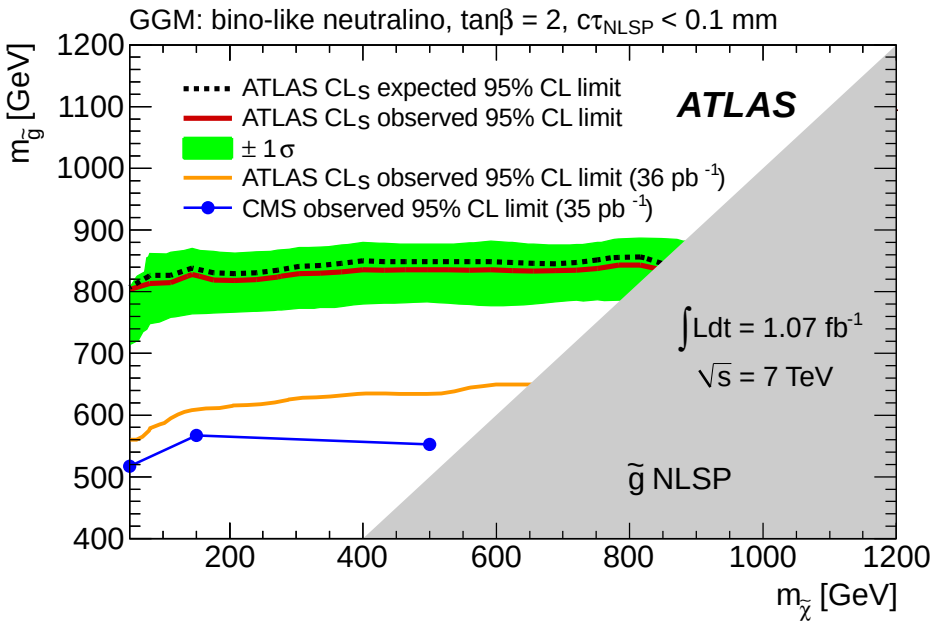
- ATLAS-CONF-2012-047
- Analysis designed to probe higgsino-like NLSP GGM models
- Dominant NLSP decay: $\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$
- Dilepton selection, requiring $81 < m_{\ell\ell} < 101$ GeV
- SRs: $p_T(Z)$, jet multiplicity, H_T, E_T^{miss}
- Major SM backgrounds: $t\bar{t}$, Z + jets
  - $t\bar{t}$background derived from MC simulation
  - Z + jets background acquired via a data-driven E_T^{miss} template method
    - γ + jets control sample used for Z + jets template

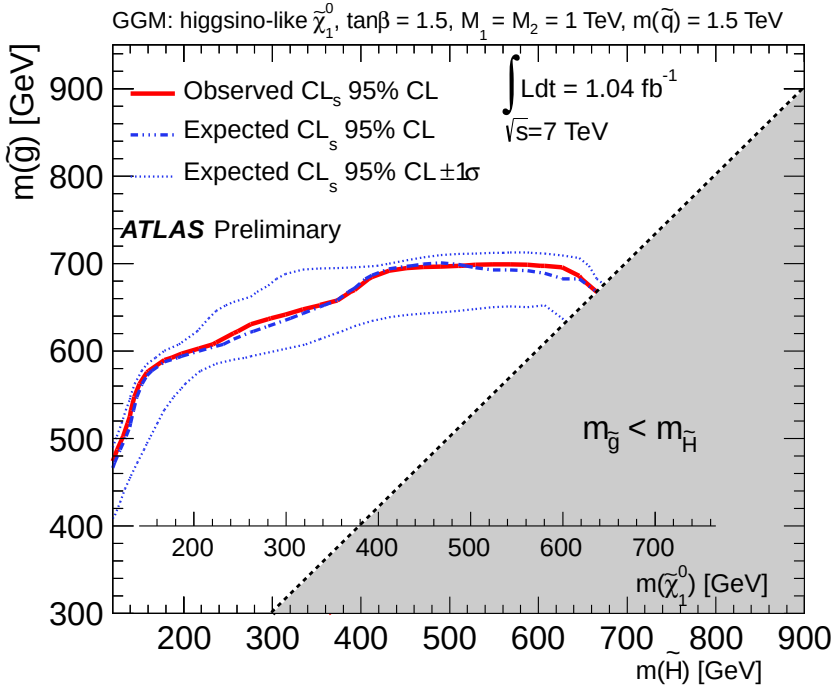


E_T^{miss} after SR2 selection in the ee channel. (without E_T^{miss} cut)

Background	SR1		SR2	
	ee	$\mu\mu$	ee	$\mu\mu$
top	0.2 ± 0.2	0.2 ± 0.1	2.2 ± 1.0	3.0 ± 1.3
dibosons	-	0.0 ± 0.1	0.8 ± 0.2	0.9 ± 0.4
Z/γ^* + jets	0.3 ± 0.4	0.3 ± 0.3	2.1 ± 1.2	3.2 ± 1.8
SM	0.5 ± 0.4	0.4 ± 0.3	5.2 ± 1.7	7.1 ± 2.3
Observed	2	0	4	7

- General gauge mediation (GGM)
  - Model-independant formulation of GMSB
  - No mass hierarchy between colored and uncolored states





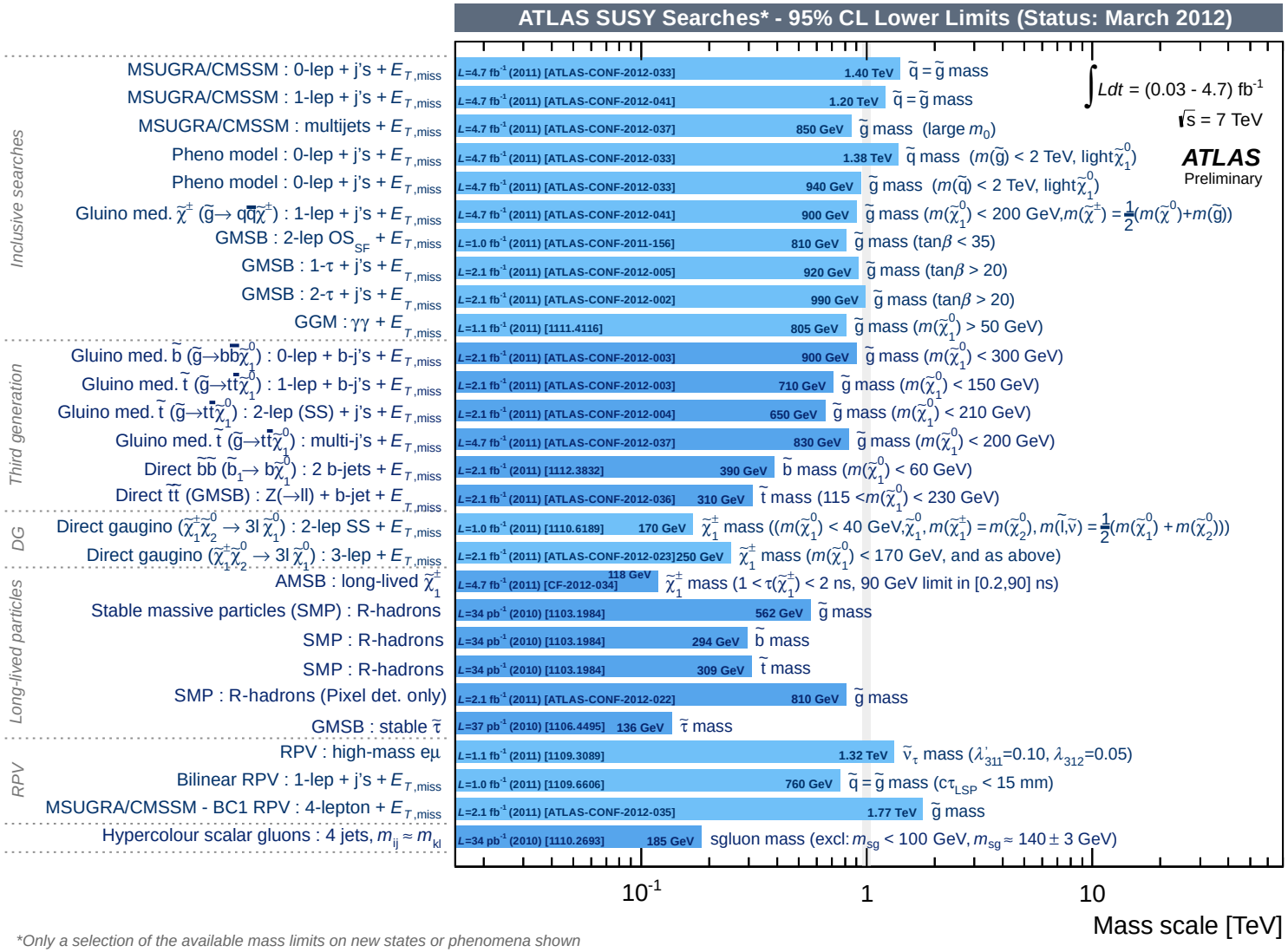
$\gamma\gamma + E_T^{\text{miss}}$

- bino-like $\tilde{\chi}_1^0$
- For $m(\widetilde{B}) \geq 150$ GeV, exclude $m(\tilde{g}) \lesssim 800$ GeV

$Z(\ell\ell) + E_T^{\text{miss}}$

- higgsino-like $\tilde{\chi}_1^0$
- For $200 < m(\widetilde{H}) < 600$ GeV, exclude gluino masses below $570 - 700$ GeV

Status of ATLAS SUSY searches



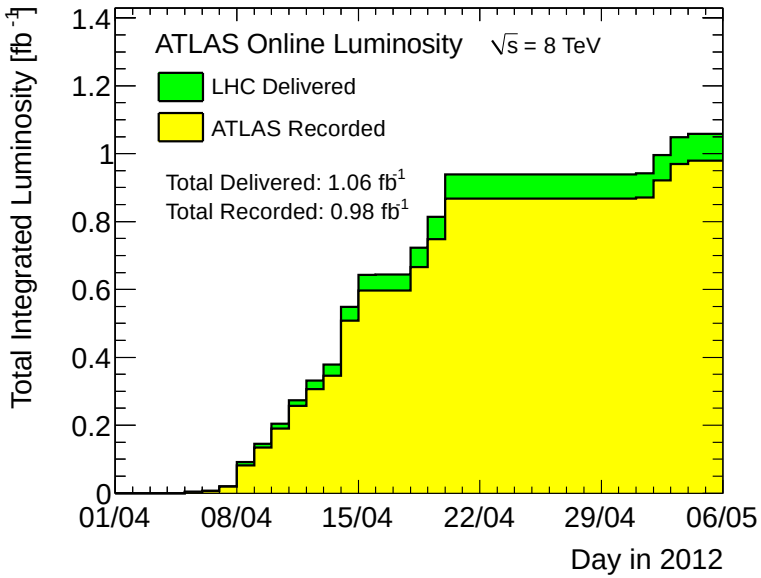
*Only a selection of the available mass limits on new states or phenomena shown

Up to the ∼TeV scale, no hint of new physics yet...

- ATLAS SUSY: a very vibrant and productive search program!
- Many complementary search channels
- Sophisticated analysis techniques employed, including simultaneous fits across multiple selection regions
- No hints of new physics with 5 fb^{-1} of 2011 $\sqrt{s} = 7$ TeV data
- Analyses finalizing publications on 2011 data

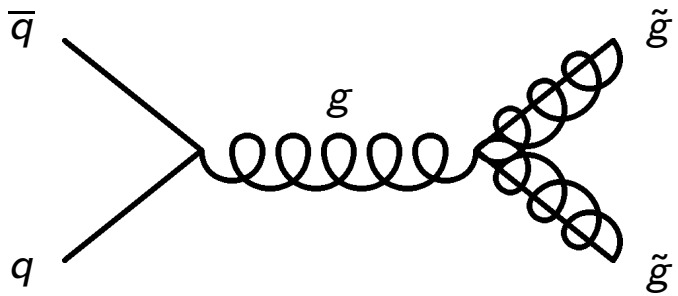
2012 $\sqrt{s} = 8$ TeV data is already here!

- ATLAS has recorded $\sim$1 fb^{-1} in 2012
- 0- and $\geq$ 1-lepton searches planning updates by end of summer
- Many other search channels actively pursuing searches with 2012 data!
  - Including direct stop production, direct gaugino production, RPV searches



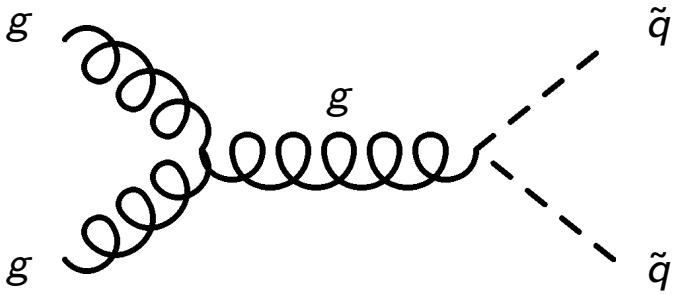
Backup

Strong SUSY particles are Pair-produced ($\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, $\tilde{g}\tilde{g}$):



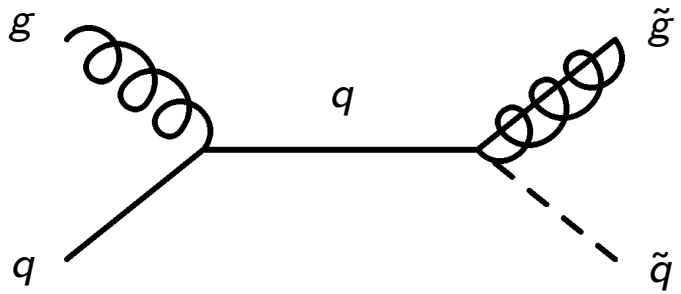
$m(\tilde{g}) \approx m(\tilde{q})$

- Squarks & gluinos produced
- $\geq$ 3 jets



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

- Gluino production dominant
- $\geq$ 4 jets

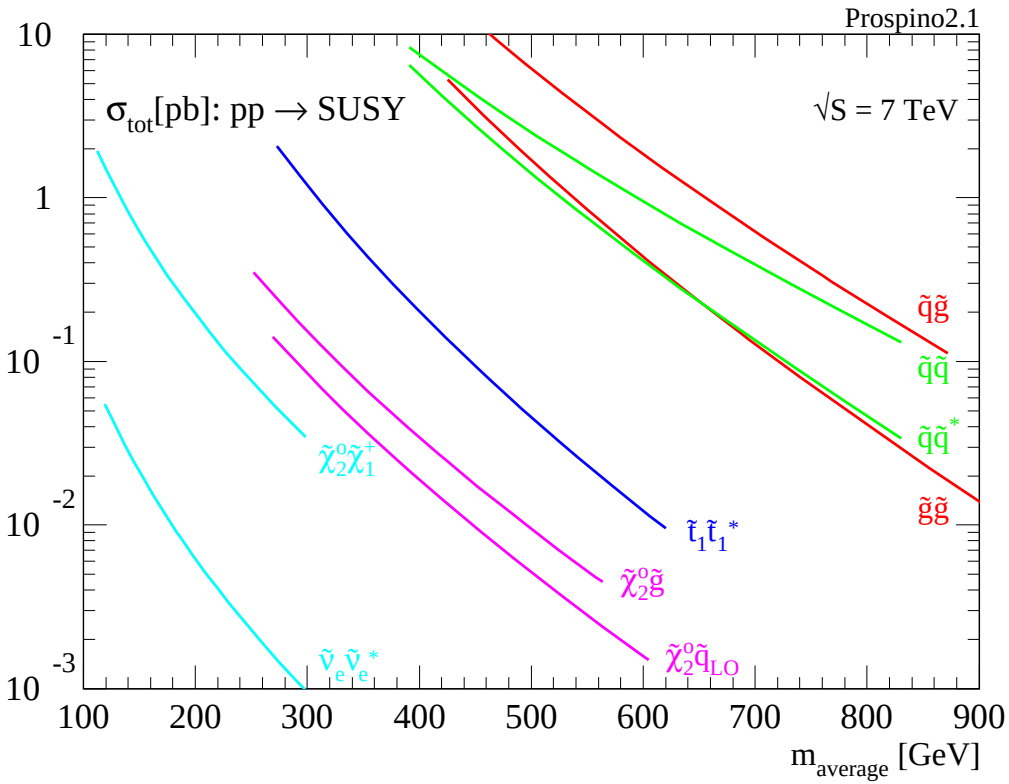


$m(\tilde{g}) > m(\tilde{q})$

- Squark production dominant
- $\geq$ 2 jets

Different production mechanisms lead to different phenomenologies and SRs.

SUSY production characterized by strong production of squarks ($\tilde{q}$) and gluinos ($\tilde{g}$)



These decay either directly to the LSP or in cascades of other MSSM particles

Interpretation in a grid of SUSY models

In the minimal SUSY extension of the SM (MSSM), there are an un-manageable number of free parameters: (105+19)

Need a way to formulate models in an easier fashion

- Top-down approach (SUSY breaking models)
  - Popular frameworks: gravity mediation (mSUGRA), gauge mediated SUSY breaking (GMSB), general gauge mediation (GGM)
  - Fix a small set of parameters to some values at a higher energy scale than observable
  - Extrapolate back to electroweak scale & predict the phenomenology
- Bottom-up approach
  - Phenomenological models
    - Assume some sparticle mass hierarchy
  - Simplified models
    - Consider individual decays as building blocks for the model

Model independent limits on visible cross-section

Can also use observations and expectations to quantify the rate of new physics, assuming the same acceptance (A) times efficiency (ϵ):

$$\sigma_{\text{vis}} = \sigma \times A \times \epsilon$$