SUSY Searches in ATLAS

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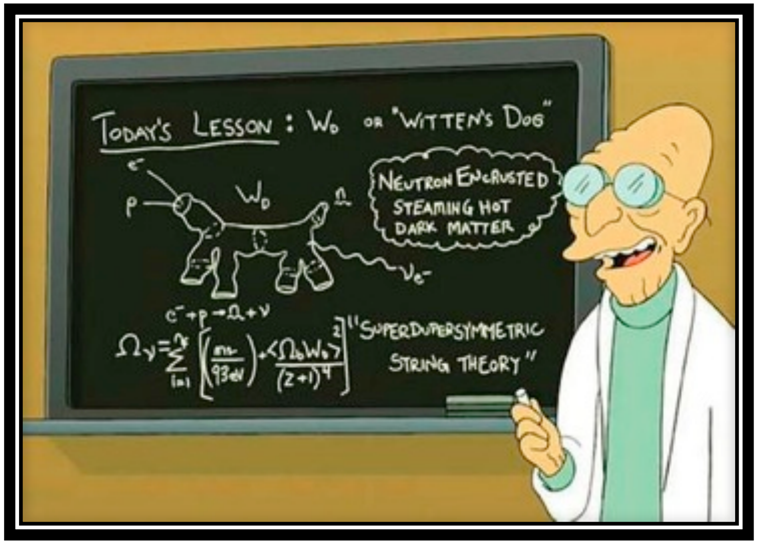
On behalf the ATLAS Collaboration

Outline

- Supersymmetry phenomenology at the LHC
- LHC operation and the ATLAS detector
- Overview of Supersymmetry searches in ATLAS
- Conclusions and outlook

Links to Webpages:
ATLAS results
ATLAS SUSY results



SuperSymmetry (SUSY) Introduction

One of the most popular extensions of the SM

✓SUSY postulates "superpartners" to each SM particles

✓Higgs sector extended to 5 Higgs

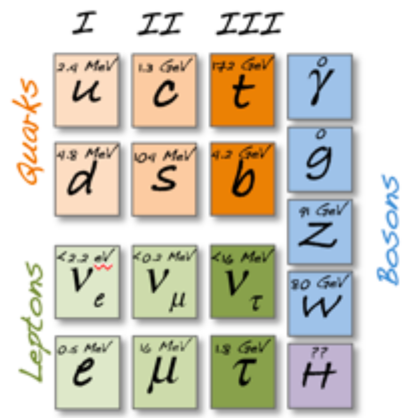
Why is SUSY popular ? It answers many open questions at once:

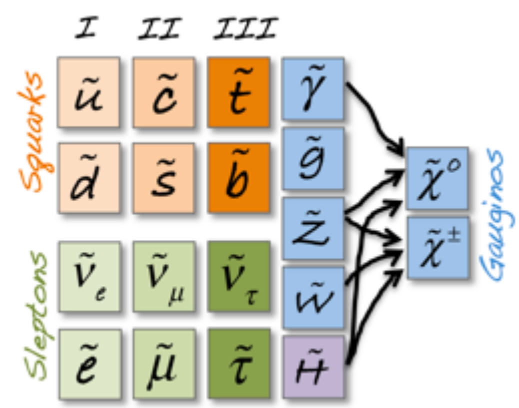
✓Provides a solution to the hierarchy problem

- The fermion/boson contributions to the Higgs mass exactly cancel

✓Allows unification of gauge couplings

✓Offers a dark matter (DM) candidate





The SUSY experimental challenge:

✓ SUSY is very predictive in terms of spins and couplings, but tells us nothing about the masses <u>after symmetry breaking</u>

✓ Results: 124 free parameters !

- All possible mass hierarchies between SUSY particles: 9! models

✓ Unknown mass hierarchy determines decay chain and (possibly long) lifetimes

So where do we start ?

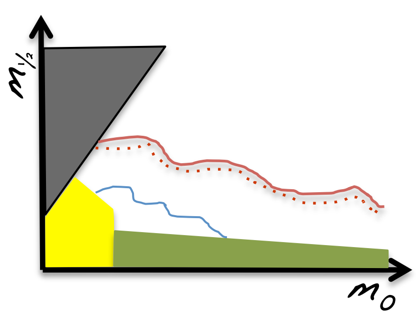
Modeling SUSY

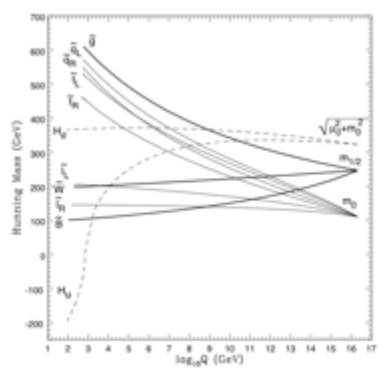
Top-down approach:

- Model of SUSY breaking:
  - Gravity mediated (mSUGRA, cMSSM)
  - Gauge mediated (GMSB)
  - …
- Assume GUT scale parameters (few)

  - m_0: scalar mass parameters
  - $m_{1/2}$: gaugino mass parameter
  - A_0: trilinear Higgs-sfermion-sfermion coupling
  - $\tan\beta$: ratio of Higgs vacuum expectation values
  - sign(μ): sign of SUSY Higgs parameter

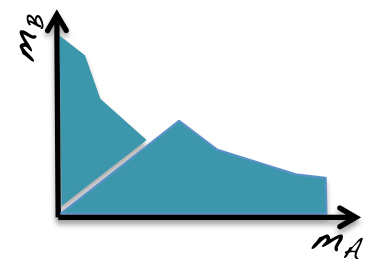
- Predict phenomenology at the EWK scale



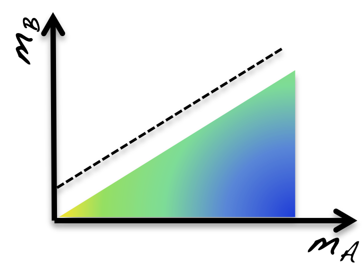


Bottom-up approaches:

- Phenomenological models:
  - Assume mass & hierarchy for SUSY particles



- Simplified models:
  - Well define production & decay
  - Assume simple decay chain



Model Independent limits:

- Provide:
  - σ × selection efficiency × detector acceptance

Expected Signatures

General MSSM Lagrangian violates leptonic and baryonic numbers in the superpotential → Introduce new symmetry to suppress proton decay

R-Parity

$R = (-1)^{3(B-L)+2s}$

$R_p^{SM} = +1$

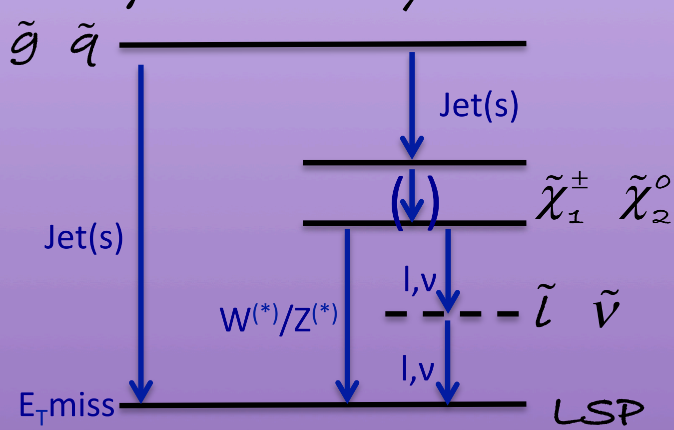
$R_p^{SUSY} = -1$

Impact on expected phenomenology

R-Parity Conservation (RPC)

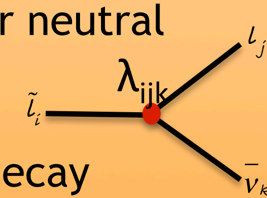
- ✓ SUSY particles created in pairs
- ✓ Lightest Supersymmetric Particle (LSP) is stable. DM candidate.
  - ✓ Missing transverse momentum ($E_T$miss)
  - ✓ No mass peak: SUSY evidence in tails of distributions

Simplified Decay Chains



R-Parity Violation (RPV)

- ✓ LSP: not need to be stable nor neutral
  - ✓ Not DM candidate
- ✓ LSP decays:
  - ✓ Exploit invariant mass, decay properties
- ✓ Sparticle can be produced singly
- ✓ $E_T$miss can also be expected (e.g neutrinos) but can be relaxed



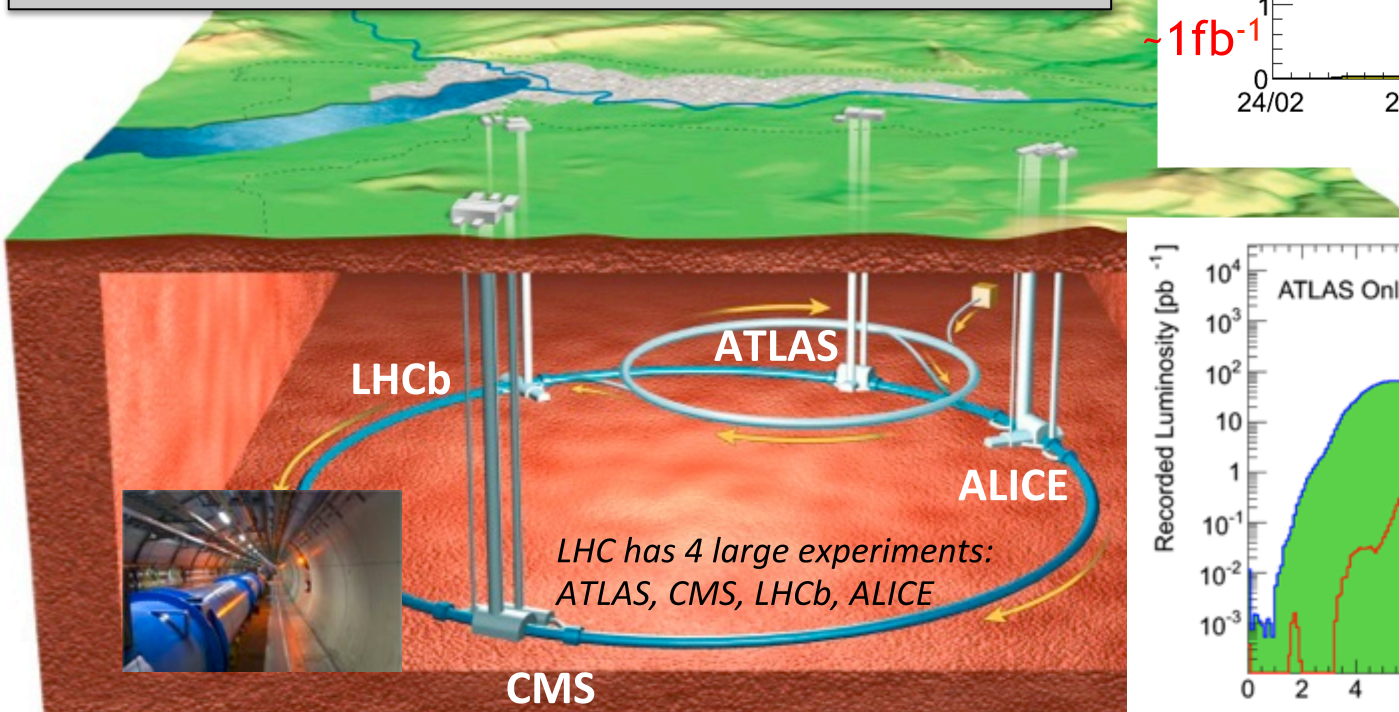
Other more exotic situations

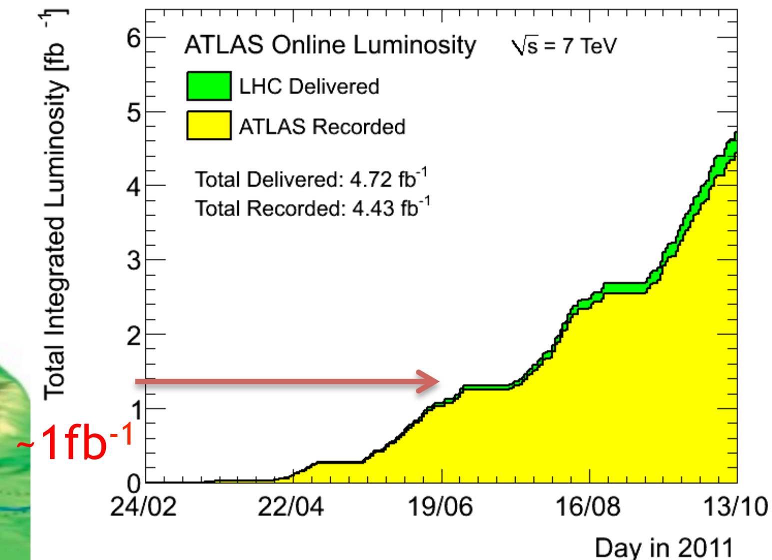
- ✓ Depending on the mass splitting/hierarchy
  - ✓ Displaced vertices
  - ✓ Slow moving ionizing particles
  - ✓ Delayed decay
  - ✓ …

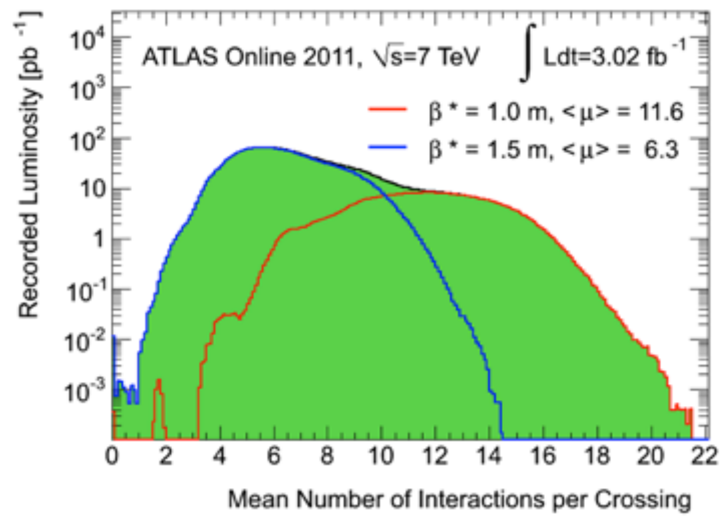
The Large Hadron Collider

In 2011

2011 LHC facts
- pp collider at 7 TeV center-of-mass energy
- Currently (Oct 2011):
  - Operating Peak Luminosity: **3.4×10^{33} $cm^{-2}s^{-1}$**
  - Max integrated luminosity per fill ~**60 pb^{-1}**
  - **~12 collisions per bunch crossing (~6 in July)**
  - Bunch spacing: **50 ns**
  - **1331 bunches** colliding in ATLAS





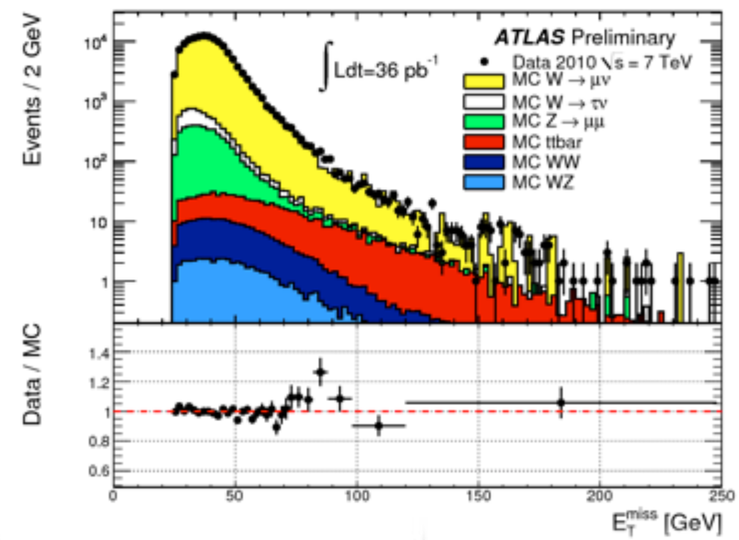


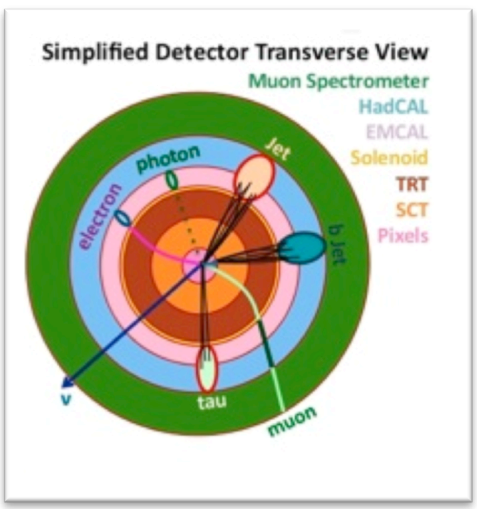
The ATLAS Detector

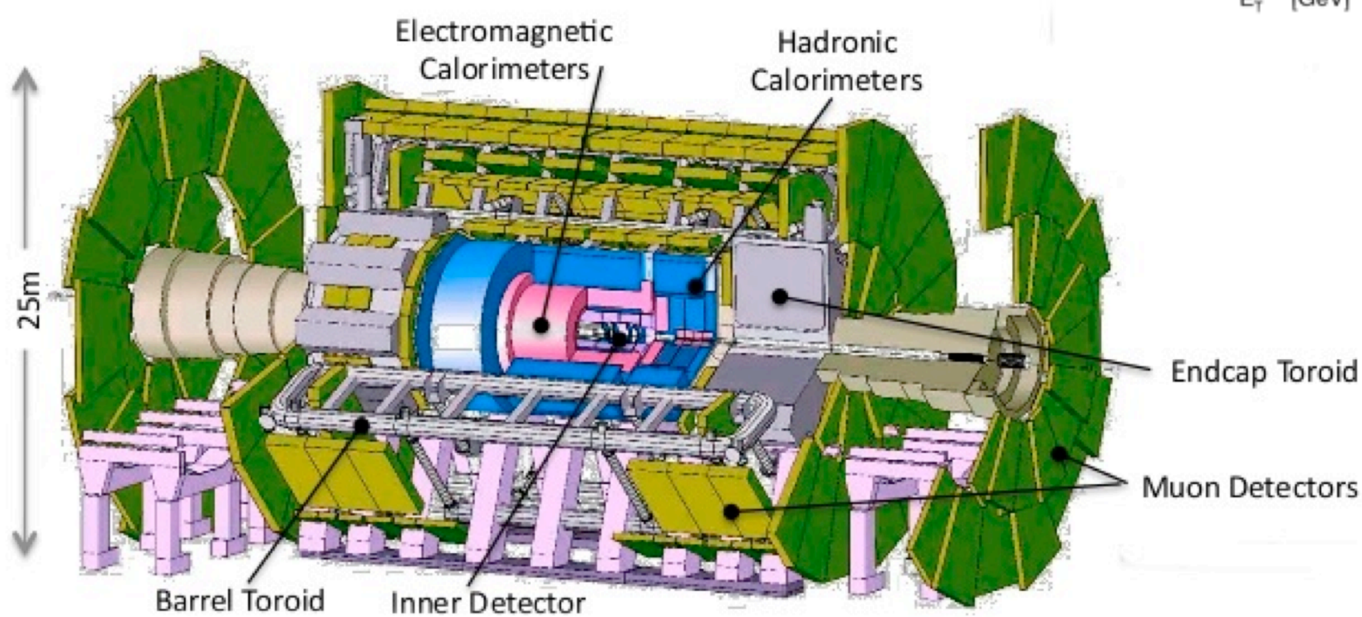
Multipurpose multi-layered detector

- Design specifications
  - ✓ Fast response and fast readout
  - ✓ High granularity
  - ✓ Radiation resistant
- Performance specifications
  - ✓ Large acceptance and hermeticity
  - ✓ Excellent jet and E_T^{miss} resolution
  - ✓ Excellent particle identification
  - ✓ Excellent vertex reconstruction
  - ✓ Standalone muon measurement

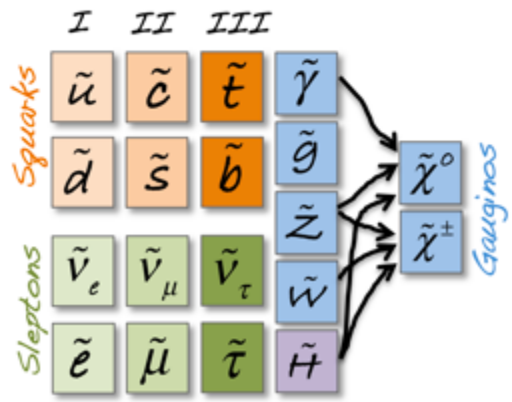
E_T^{miss} in $W \rightarrow \mu\nu$

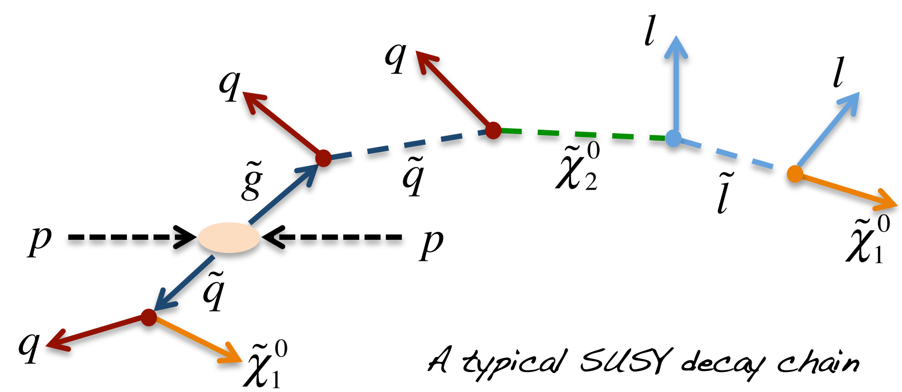






Analyses Outline





A typical SUSY decay chain

Rich Phenomenology:

- ✓ Short/long decay chain
- ✓ With/without sleptons
- ✓ Different flavors of jets/leptons
- ✓ Large/small $E_T$miss

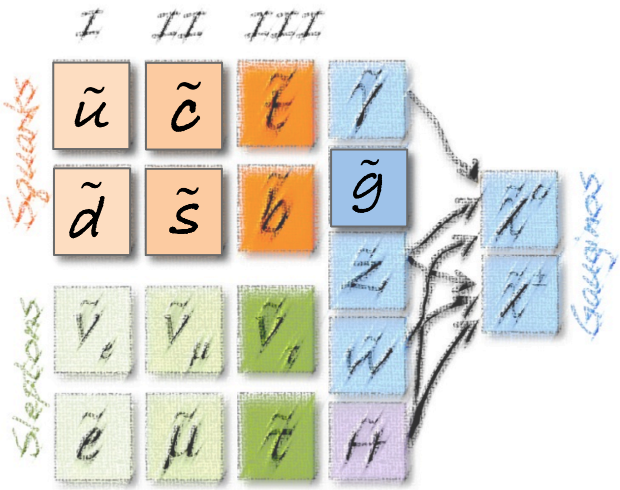
R-Parity Conserving searches (RPC)

- ✓ 0-lepton
- ✓ 1-lepton
- ✓ 2-leptons
- • Multi-leptons
- ✓ b-jets searches
- ✓ Photon searches

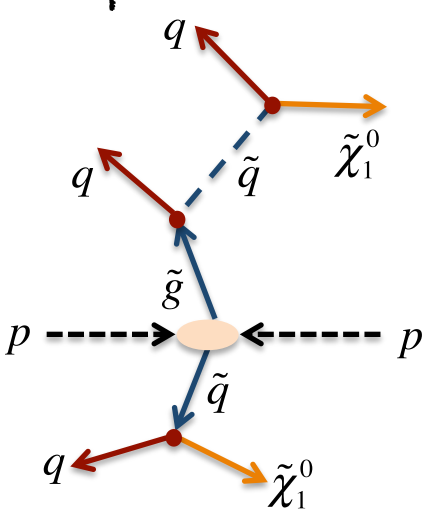
R-Parity Violating searches (RPV)

0-lepton searches

0-lepton Searches



0-lepton



<u>Strong production of massive particles:</u>

$\sigma(\tilde{g}\tilde{g}) > \sigma(\tilde{q}\tilde{g}) > \sigma(\tilde{q}\tilde{q})$ for $m(\tilde{g}) < 800$ GeV

$\tilde{g} \to qq\tilde{\chi}_0^1$; $\tilde{q} \to q\tilde{\chi}_0^1$

Jet+$E_T$miss signature (hadronic τ treated as jets)

Veto leptons

<u>Background control challenging:</u>

- High multi-jet cross section
  - Need data-driven background estimate
- Low signal Efficiency×Acceptance

<u>Objects definition</u>

Jet

Anti k_T ΔR=0.4
p_T>20 GeV, |η|<2.8

$E_T$miss

Vectorial sum of all jets and leptons
Cluster not belonging to any jets added to the $E_T$miss

Electron

p_T>20 GeV; |η|<2.47

Muon

p_T>10 GeV; |η|<2.4

2 analysis strategies:

- Excess at large $E_T$miss
- Excess at large jet multiplicities

Signal regions selection

- Depending on the SUSY mass hierarchy, different production processes favored $\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$
- To maximize $m_{\tilde{g}}, m_{\tilde{q}}$ coverage, defines 5 signal regions optimized using a simplified SUSY model

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

Trigger Plateau (E_T^{miss}, leading jet p_T)

Jet multiplicity (second, third and fourth jet p_T)

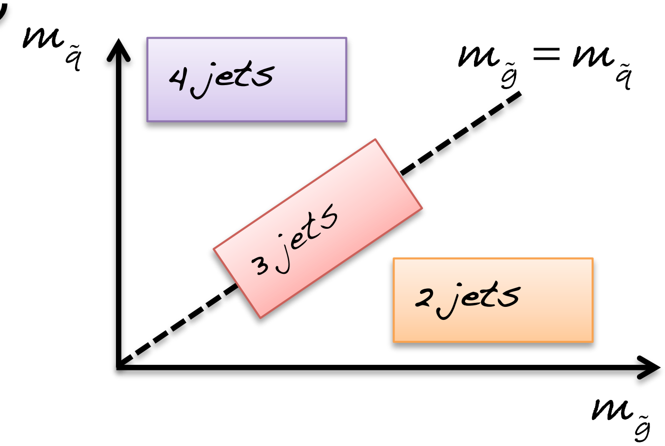
QCD rejection ($\Delta\phi$)

Signal enhancement (E_T^{miss}/m_{eff}, m_{eff})

≥ 2-jet: $\tilde{q}\tilde{q}$; ≥ 3-jet: $\tilde{g}\tilde{q}$; ≥ 4-jet and High mass: $\tilde{g}\tilde{g}$

$$m_{eff} \equiv \sum_{i=1}^{n} \left|p_T^i\right| + E_T^{miss}$$

Combine the 5 channels to optimize the search for different topologies



Background estimate overview

Background Sources	
QCD jets	Mis-measurement of jets or ν in H.F decay
Z+jets	Irreducible $Z \rightarrow \nu\nu$
W+jets	Lepton measured as jets or not reconstructed
top	Hadronic τ decay
All background estimations are data-driven	

- Method:
  1. Define 5 Control Regions (CR) for each five signal regions (SR)
     - Each CR enriched in particular background source (>50% purity)
     - 1-channel: 1 SR & 5 CR's
  2. Input to combined profile likelihood fit
     - Accounts for correlated systematic uncertainties and mutual background contamination in CR
  3. Extrapolate from CR to SR using Transfer Factors (TF) for each background process. TF's are computed using a mix of data-driven and MC driven techniques.

QCD background estimate

- $E_T$miss origin in QCD multi-jets due to:
  - Jet mis-measurement
  - Heavy flavors leptonic decays

  } $E_T$miss aligned with one of the jets

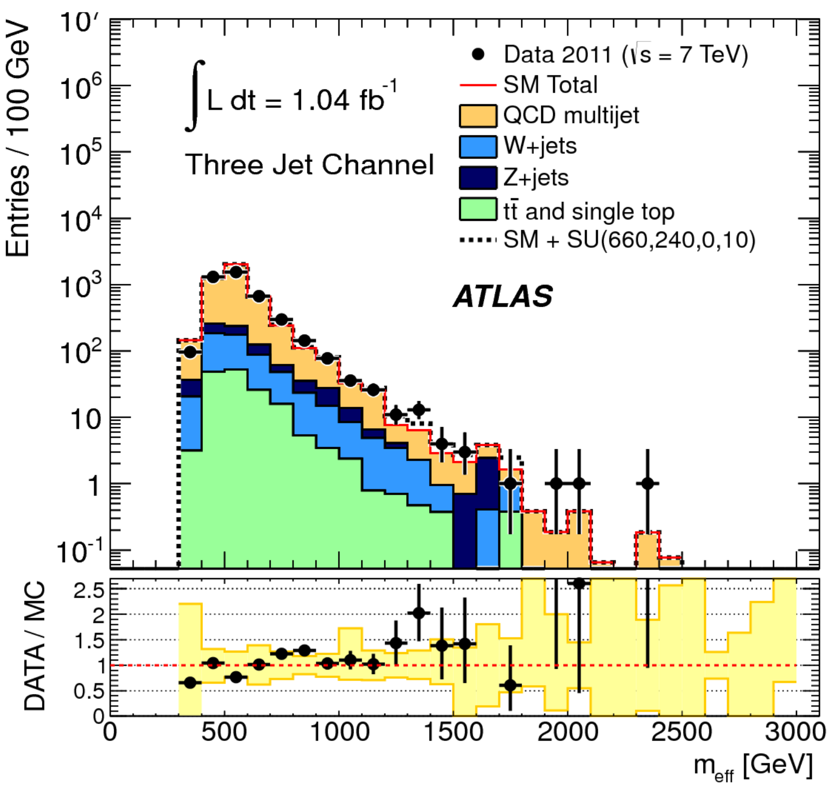
- Transfer Factor obtained by smearing low $E_T$miss events with a jet response function

- Validation:
  - QCD prediction from pseudo-events compared to data in event with

$$\Delta\phi_{min}(jet, E_T miss) < 0.4$$

- Uncertainties from modeling jet smearing

QCD CR

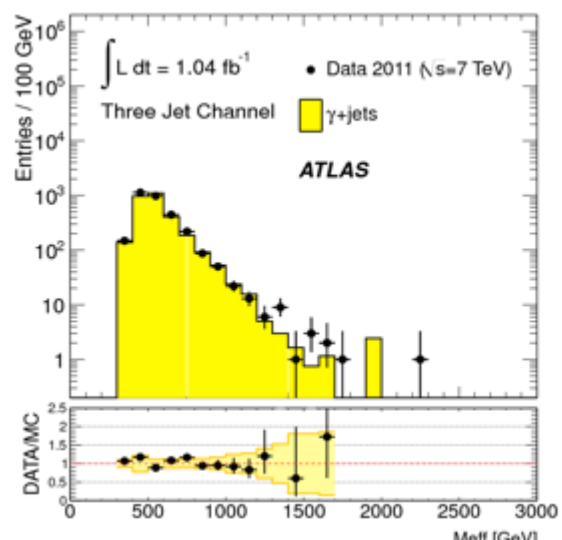


Z+jets background estimate

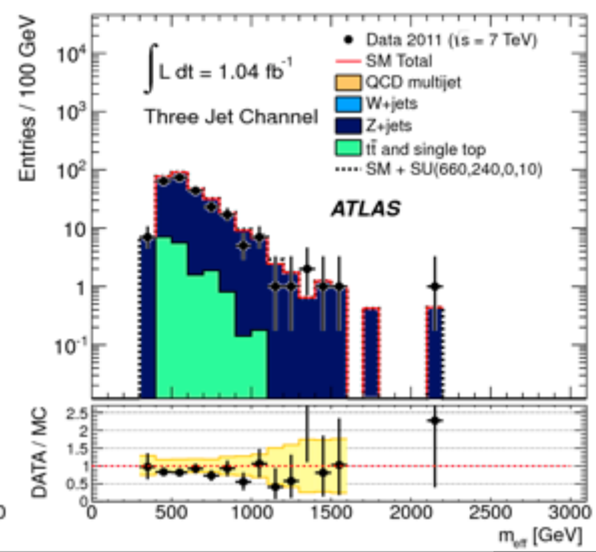
- $Z \to \nu\nu$ is the dominant component of the the total Z background
- Estimate performed in 2 CR's (in both cases, replace the boson with $E_T$miss)
  - γ+jets events
    - use robustness of $$R_{Z/\gamma} = \frac{d\sigma(Z + jets)/dp_T}{d\sigma(\gamma + jets)/dp_T}$$
  - Z(ee+μμ)+jets

- Main uncertainties:
  - Theoretical extrapolation
  - Jet E-scale/resolution
  - MC statistics

γ+jets CR



Z+jets CR

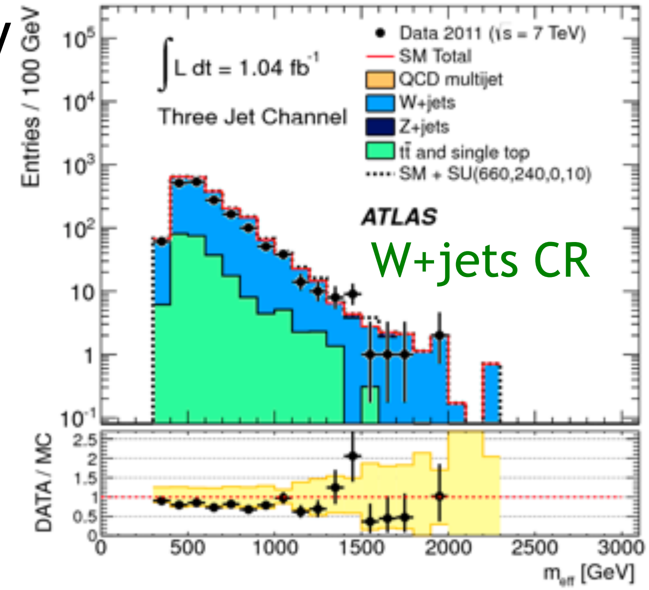


W+jets & top background estimate

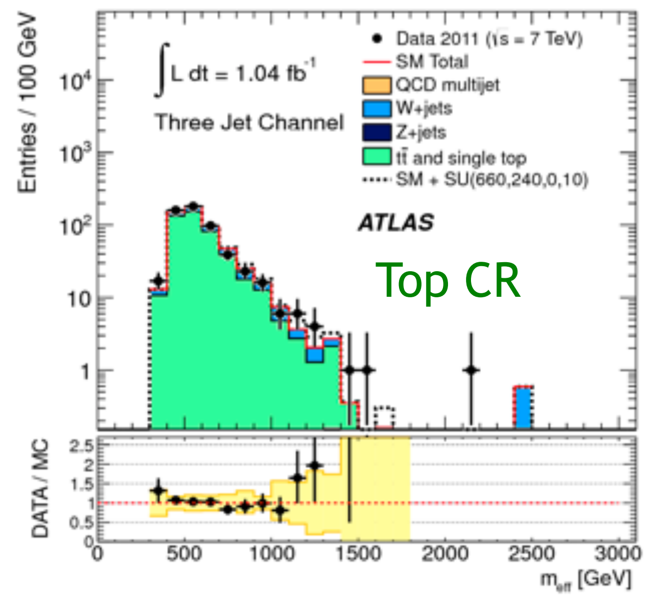
- CR events selected with a lepton + $E_T$miss>130 GeV (leptons treated as jets)
  - 30 <m_T<100 GeV

$$m_T = \sqrt{2 \times p_T^{lep} \times E_T miss \times \left(1 - \cos \Delta\phi_{lep,E_T mis}\right)}$$

  - b-tagged jet ➔ Top CR
  - b-tagged veto ➔ W CR

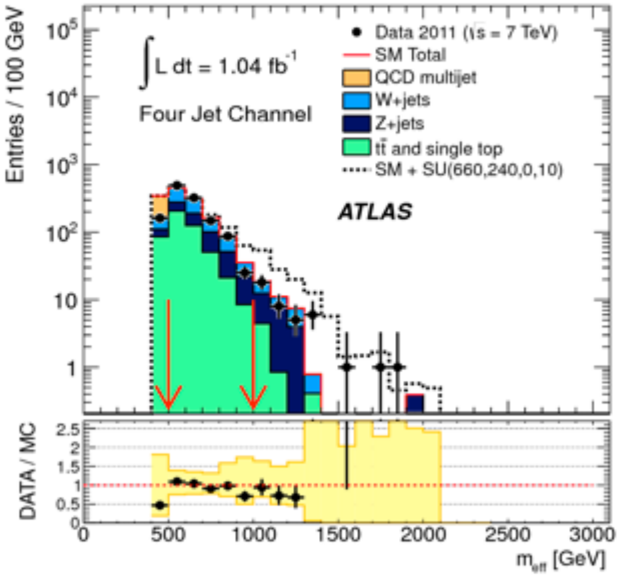


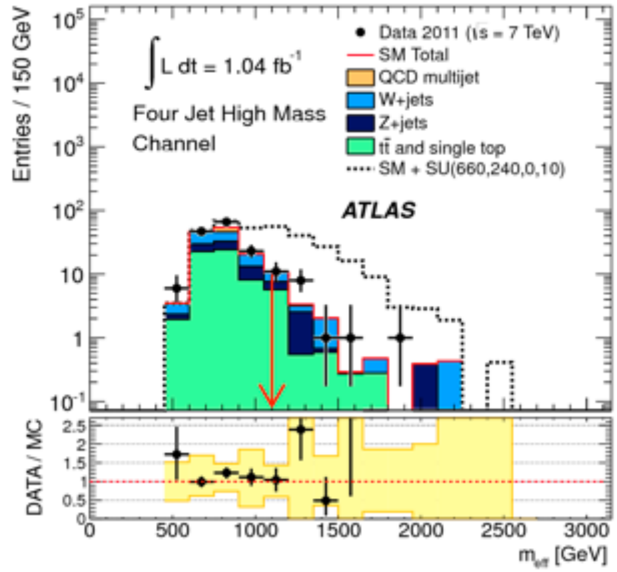
- Transfer factor from simulation

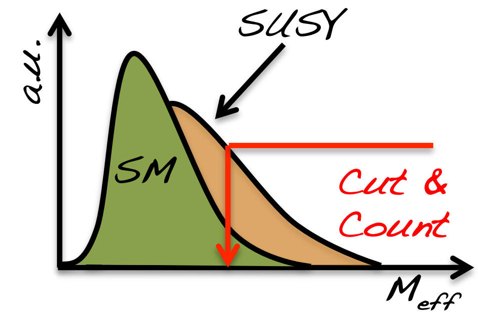


- Main uncertainties:
  - Theoretical expectations
  - Jet energy scale/resolution
  - Pileup
  - B-tagging uncertainties
  - MC statistics

0-lepton results







Process	≥2-jets	≥3-jets	≥4-jets M_{eff}>500 GeV	≥4-jets M_{eff}>1000 GeV	High mass
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

Result is interpreted as a 95% C.L. exclusion limit on fiducial cross sections (CLs)

≥2-jets	≥3-jets	≥4-jets M_{eff}>500 GeV	≥4-jets M_{eff}>1000 GeV	High mass
22 fb	25 fb	429 fb	27 fb	17 fb

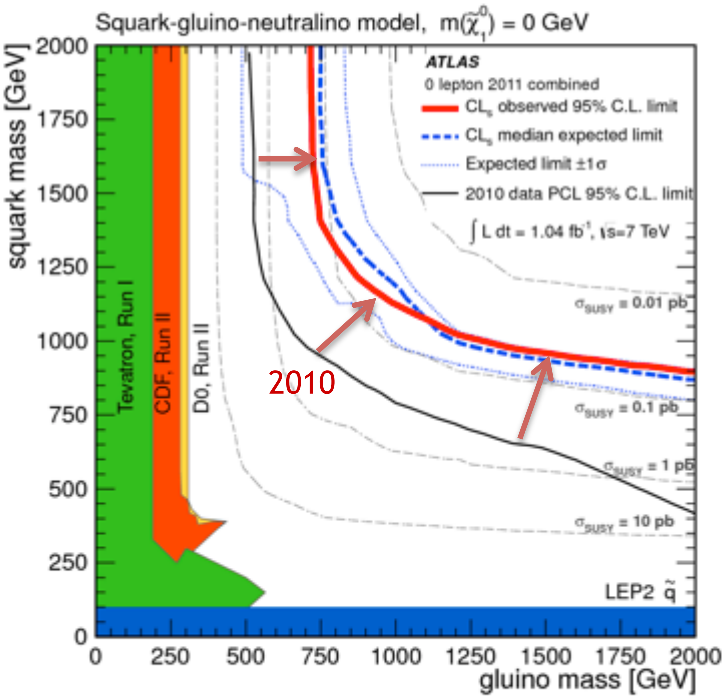
Best expected signal region per model point is chosen

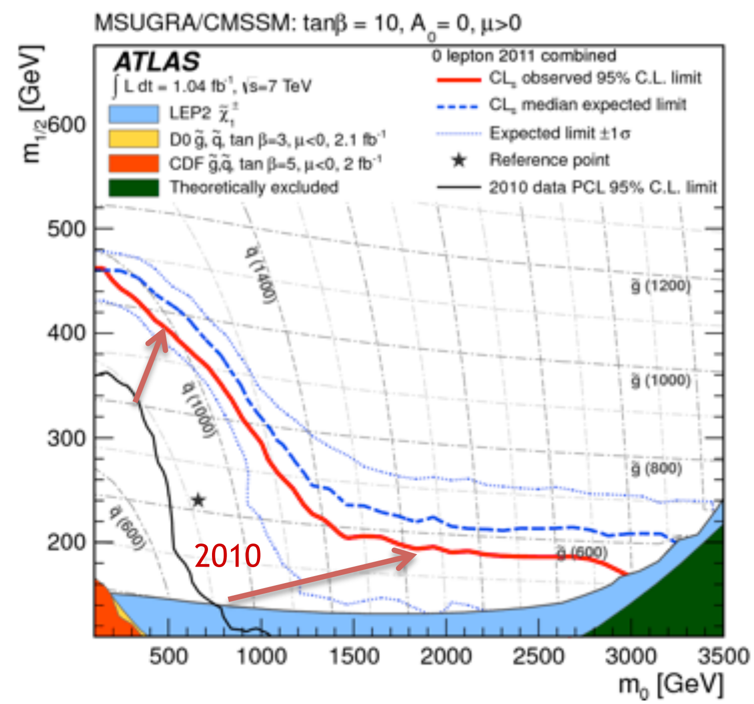
1.04 fb^{-1} 0-lepton search interpretation

<u>Phenomenological MSSM squark-gluino grids:</u>

- ✓ masses from 100 GeV to 2 TeV, neutralino mass of 0
- ✓ Limits unchanged if LSP mass raised to 200 GeV

<u>MSUGRA/CMSSM A_0=0, tanβ=10, μ>0</u>





Exclude at 95% C.L

$m_{\tilde{g}} \leq 700$ GeV $m_{\tilde{q}} \leq 875$ GeV

If $m_{\tilde{g}} = m_{\tilde{q}}$, masses < 1075 GeV

Exclude at 95% C.L

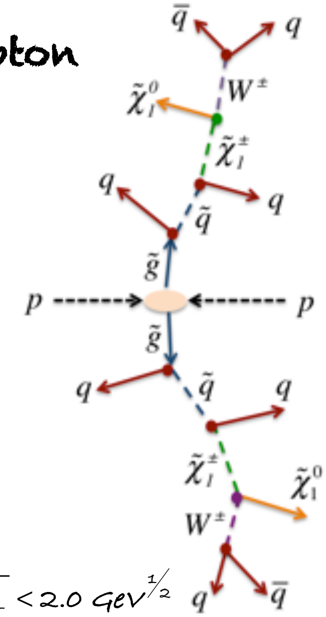
If $m_{\tilde{g}} = m_{\tilde{q}}$, masses < 950 GeV

Large jet multiplicity search

Extension of the 2-4 jet analysis: ≥6 to ≥8 jets + $E_T$miss

- Increases sensitivity to many-body or cascade decays
  - E.g. high m_0 region in cMSSM/mSUGRA

0-lepton



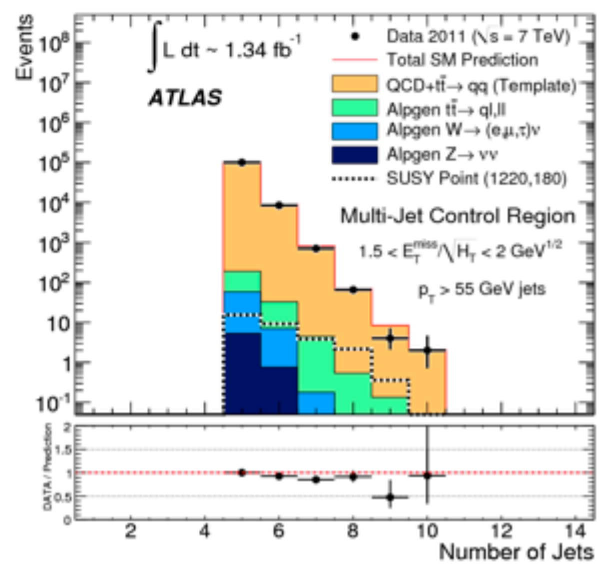
Signal region	7j55	8j55	6j80	7j80
Jet p_T	> 55 GeV		> 80 GeV	
Jet $\|\eta\|$	< 2.8			
ΔR_{jj}	> 0.6 for any pair of jets			
Number of jets	≥ 7	≥ 8	≥ 6	≥ 7
$E_T^{\rm miss}/\sqrt{H_T}$	> 3.5 GeV$^{1/2}$			

} Trigger Plateau (Jet p_T, Jet $|\eta|$, ΔR_{jj})

← SR definition (Number of jets)

← Background reduction ($E_T^{\rm miss}/\sqrt{H_T}$)

$1.5 < E_T miss/\sqrt{H_T} < 2.0$ GeV$^{1/2}$



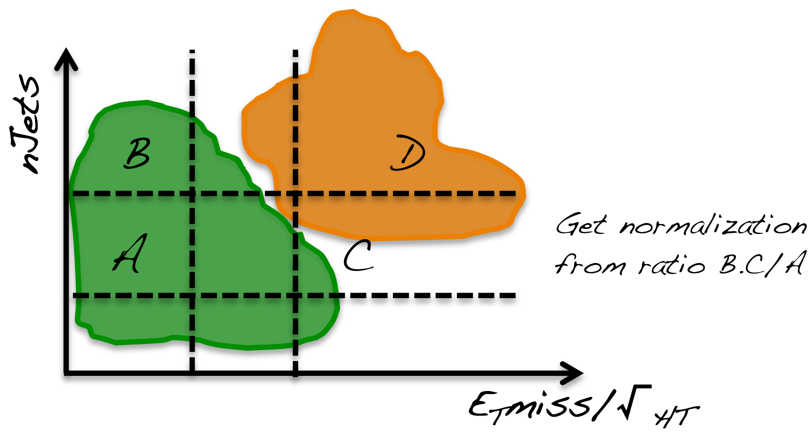
Key observation variable: $E_T$miss/$\sqrt{H_T}$ $\quad H_T = \sum_{p_T>40,\,|\eta|<2.8} p_T$

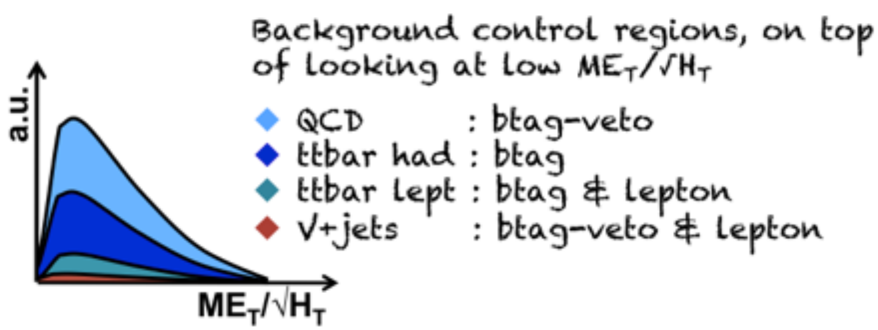
- Invariant under jet multiplicities

- Main background is multi-jet production
- Leptonic background are subdominant:

Multi-jet background estimate

$E_T$miss/√H_T shape determined from data in dedicated CRs with lower jet multiplicities

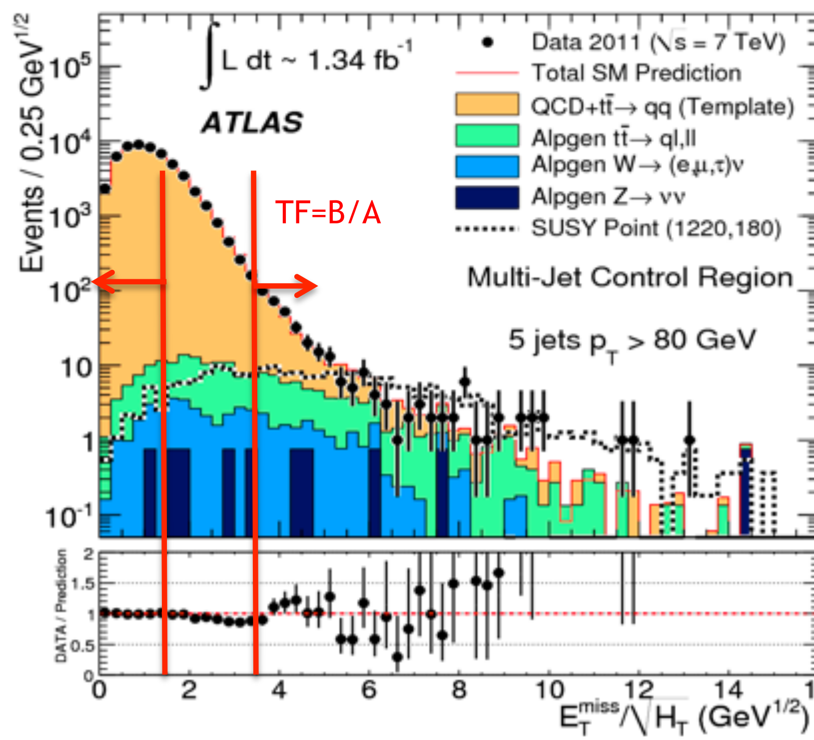




For QCD, additional validation using the smear jet technique used in 0-lepton analysis

Validate in low $E_T$miss/√H_T and/or low N_{jets} regions

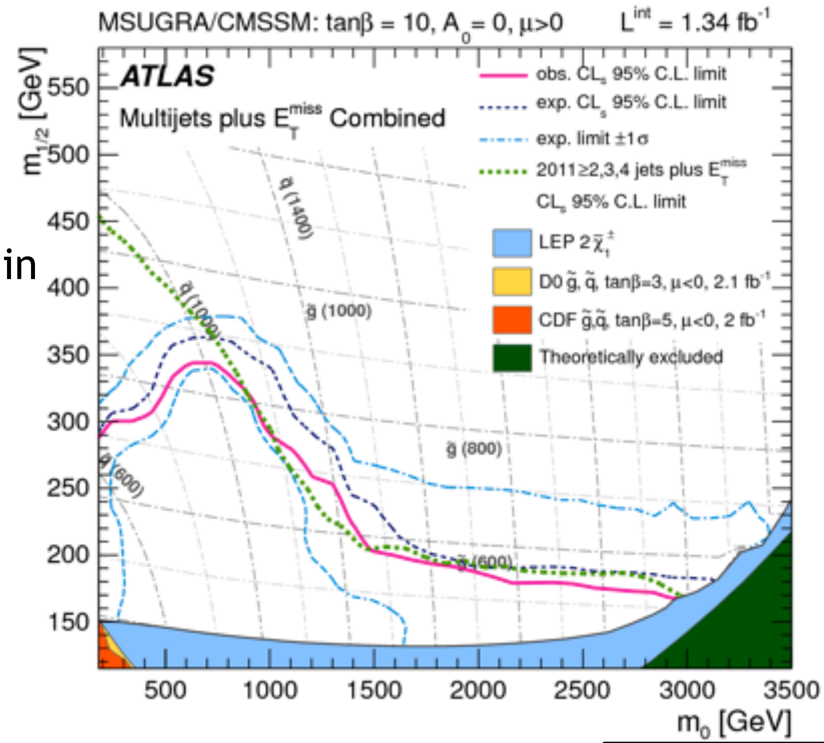
Example: exactly 5 jets with pT>80 GeV with template of 4 jets of pT>80 GeV



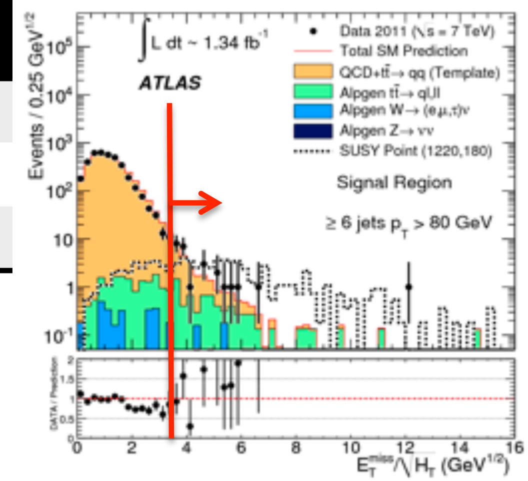
1.34 fb^{-1} Large jet multiplicity results

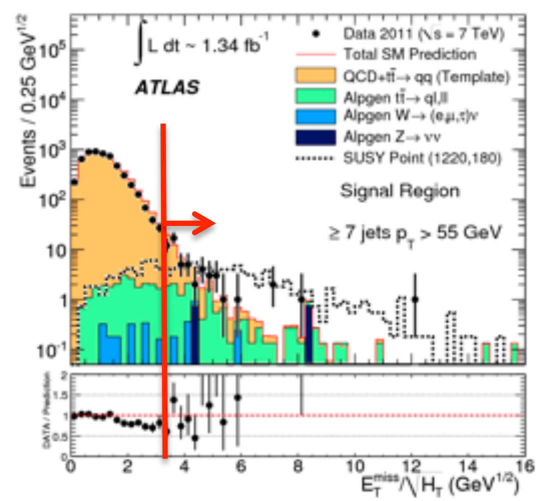
Signal region	7j55	8j55	6j80	7j80
Total	$39.3^{+8.7}_{-8.5}$	$2.3^{+4.4}_{-0.7}$	25.8 ± 6.1	$1.3^{+0.9}_{-0.5}$
Data	45	4	26	3
Fiducial σ	19.4 fb	8.4 fb	12.2 fb	4.5 fb

Best expected signal region per model point is chosen



Upward fluctuations in two key channels ➔ Exclusion less than predicted

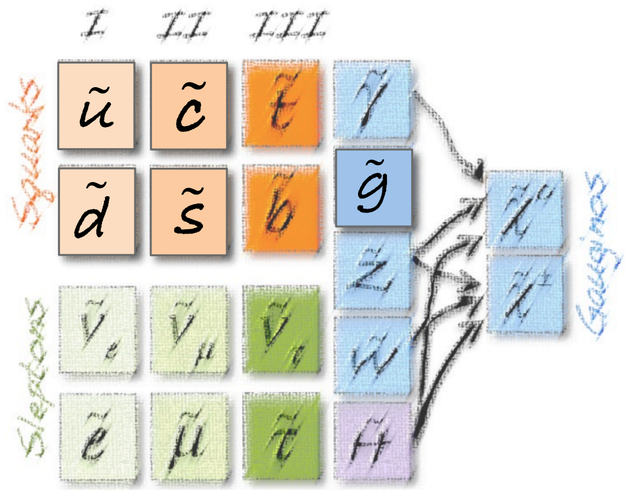




Exclude at 95% C.L $m_{\tilde{g}}$ masses < 520 GeV

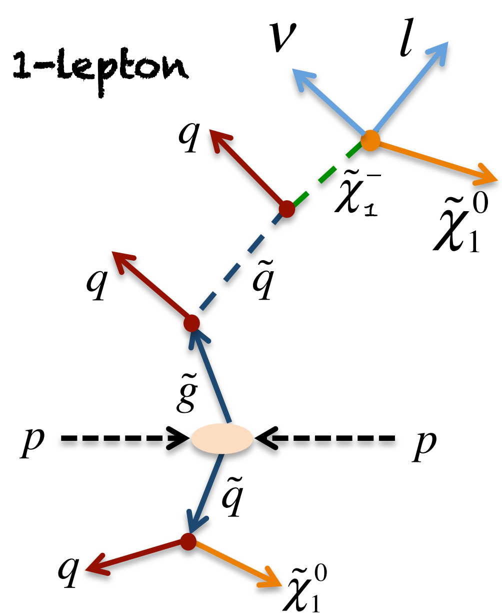
1-lepton searches

1-lepton search



- ✓ Cascades including charginos or neutralino can lead to final states with leptons
- ✓ Advantage:
  - ✓ Suppress QCD background.
  - ✓ Use lepton triggers

<u>Background sources:</u>
- Fake leptons from QCD background
- Top, W+jets



<u>Objects definition</u>

Jet
Anti k_T ΔR=0.4
p_T>20 GeV, |η|<2.8

$E_T$miss
Vectorial sum of all jets and leptons
Cluster not belonging to any jets added to the $E_T$miss

Electron
p_T>25 GeV; |η|<2.47
Isolated

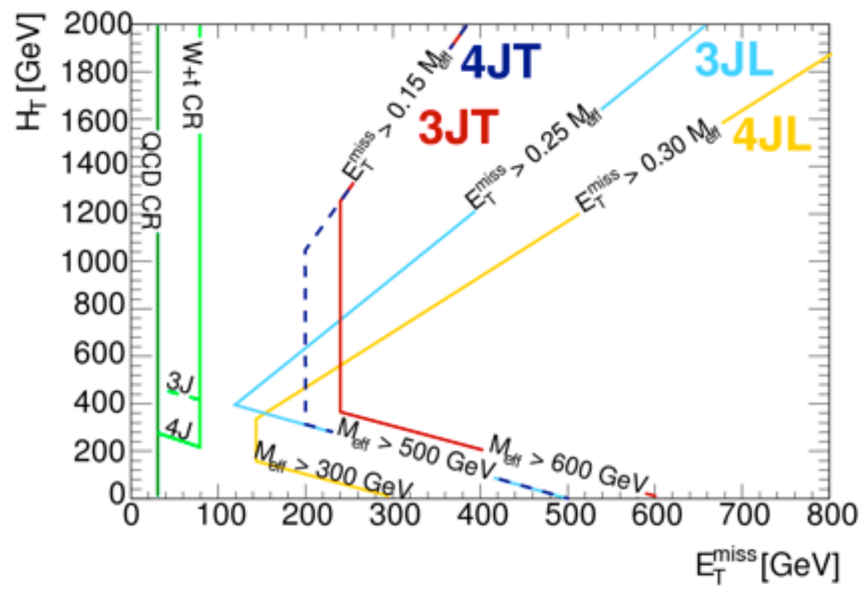
Muon
p_T20 GeV; |η|<2.4
Isolated

Signal regions selection

- Optimize signal regions
  - Tight: optimize for mSUGRA/cMSSM (characterized by high p_T jets, $E_T$miss)
  - Loose: optimize for simplified model (compressed spectra $m_{LSP} \approx m_{\tilde{q}} \approx m_{\tilde{g}}$)

Discard events with additional e(μ) p_T>20 GeV (10 GeV)

Signal region	3JL	3JT	4JL	4JL
Lepton p_T (GeV) Veto lepton p_T (GeV)	>25 (20) for e (μ) >20 (10) for e (μ)			
Number of jets	≥3		≥4	
Leading jets p_T (GeV)	60	80	60	60
Subleading jets p_T (GeV)	25	25	25	40
$\Delta\Phi(\text{Jet}_i, E_T^{miss})_{i=1,2,3,(4)}$	> 0.2			
m_T (GeV)	> 100			
E_T^{miss} (GeV)	> 125	> 240	> 140	> 200
E_t^{miss}/m_{eff}	> 0.25	> 0.15	> 0.3	> 0.15
m_{eff} (GeV)	> 500	> 600	> 300	> 500



Fake lepton background

- *Fake* lepton: jets misidentified as leptons or leptons from heavy flavor jets
- Fully data-driven estimate using loose-tight matrix method:
  - Loosen lepton selection, drop isolation

Estimated for every CR's & SR's

$$N_{Pass} = \varepsilon_{real} N_{real} + \varepsilon_{misid} N_{misid}$$
$$N_{fail} = (1-\varepsilon_{real}) N_{real} + (1-\varepsilon_{misid}) N_{misid}$$

$$N^{pass}_{misid} = \varepsilon_{misid} \times N_{misid} = \frac{N_{fail} - (1/\varepsilon_{real} - 1) N_{pass}}{1/\varepsilon_{misid} - 1/\varepsilon_{real}}$$

N_{Pass} / N_{fail} : Loose events passing/failing the tight selection

$\varepsilon_{real} / \varepsilon_{misid}$: Id and misid rate from loose -> tight

- ε_{real} : Measured from MC Z->ee (e) and W+jets/tt (μ)
- ε_{misid} : Measured from enriched QCD sample

W+jets & top background

Normalization of W & Top background derived from the CR's

1. Assume MC shapes
2. Transfer factors:

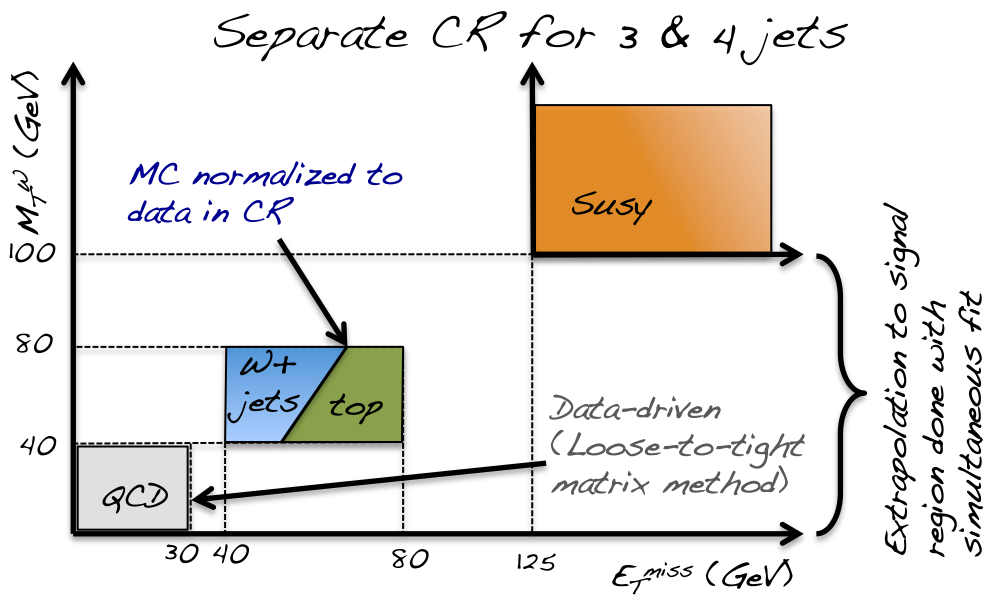
$$C_{CR \to SR} = N_{MC}^{SR} / N_{MC}^{CR}$$

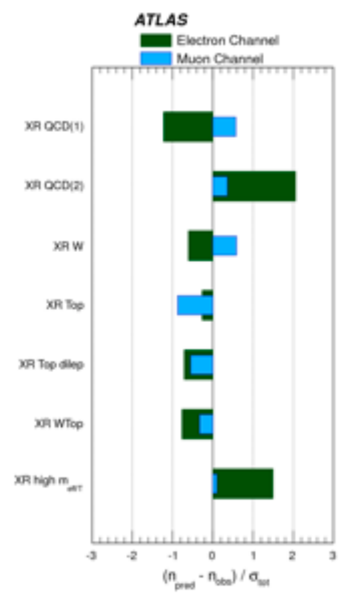
3. Extrapolate to SR:

$$N_{predicted}^{SR} = N_{data}^{CR} \times C_{CR \to SR}$$

4. Simultaneous likelihood fit of the different CR's to account for cross contamination
5. Validate procedure (MC shape assumption) in 28 additional CR's

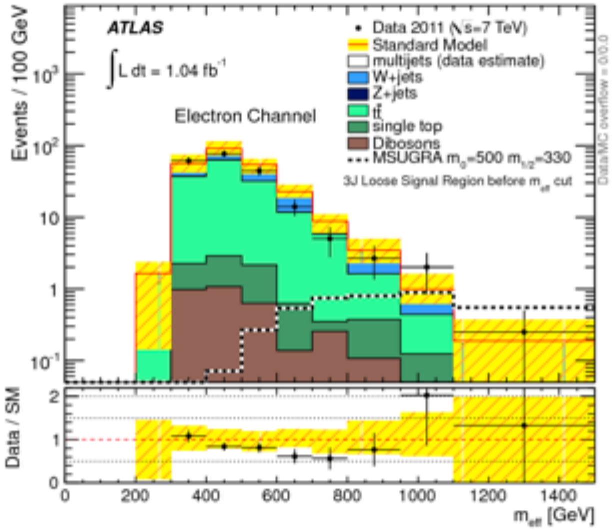
Good agreement observed between predicted and observed in every CR's

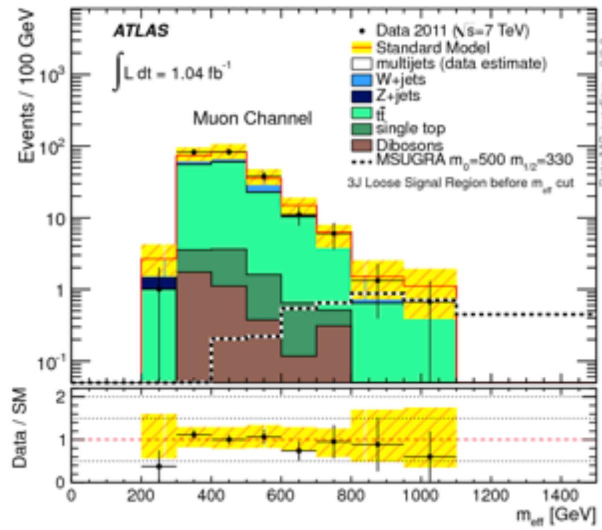


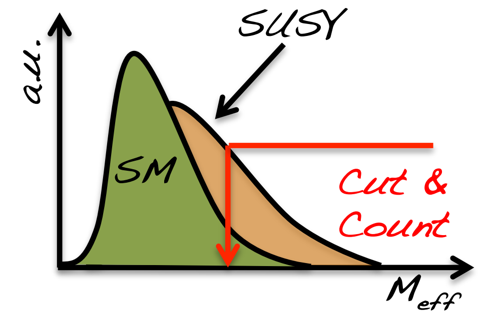


3 jets CR's

1-lepton search results







Uncertainties dominated by the JES, JER, limited MC statistics and theory uncertainty on background extrapolation

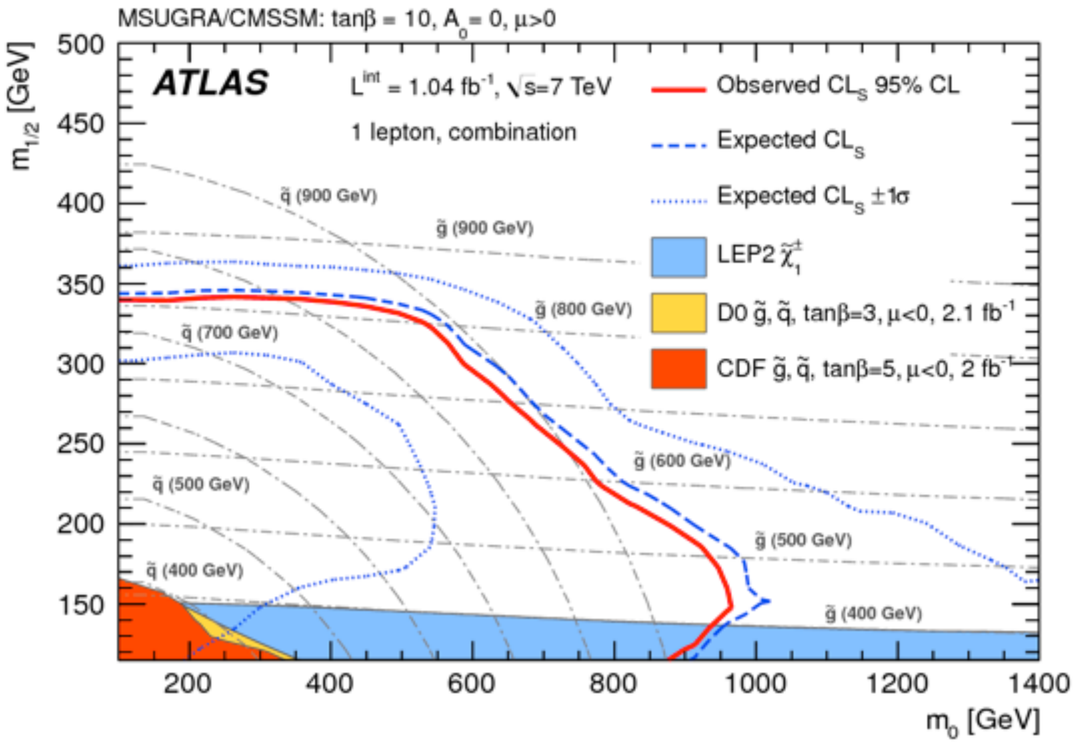
Channel	3JL	3JT	4JL	4JT
		Electron		
Predicted	97 ± 30	18.5 ± 7.4	48 ± 18	8.0 ± 3.7
Observed	71	14	41	9
		Muon		
Predicted	64 ± 19	13.9 ± 4.3	53 ± 16	6.0 ± 2.7
Observed	58	11	50	7

1.04 fb^{-1} 1 lepton search interpretation

Model independent fiducial cross section upper limit, 95% C.L.

Channel	3JL	3JT	4JL	4JT
Electron	50 fb	14 fb	33 fb	10 fb
Muon	36 fb	10 fb	31 fb	9 fb

MSUGRA/CMSSM A_0=0, tanβ=10, μ>0



Exclude at 95% C.L

$m_{\tilde{g}} = m_{\tilde{q}} < 875\,GeV$

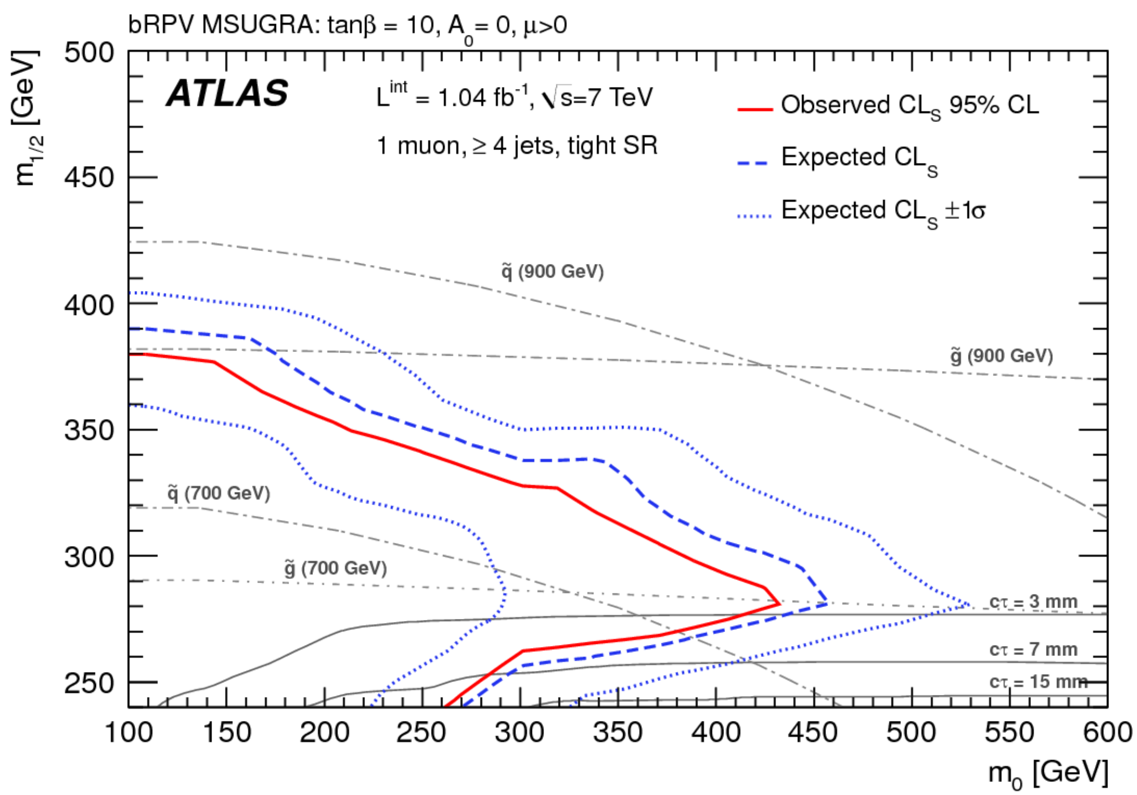
1 lepton search interpretation

bilinear RPV

Y. Grossman and S. Rakshit, Phys.Rev.D69, 093002 (2004)

- RPV model with neutralino decaying mainly to neutrino with cτ<15mm
  - Viable alternative to the origin of neutrino mass and mixing

Use muon 4TJ signal most sensitive



Exclude at 95% C.L

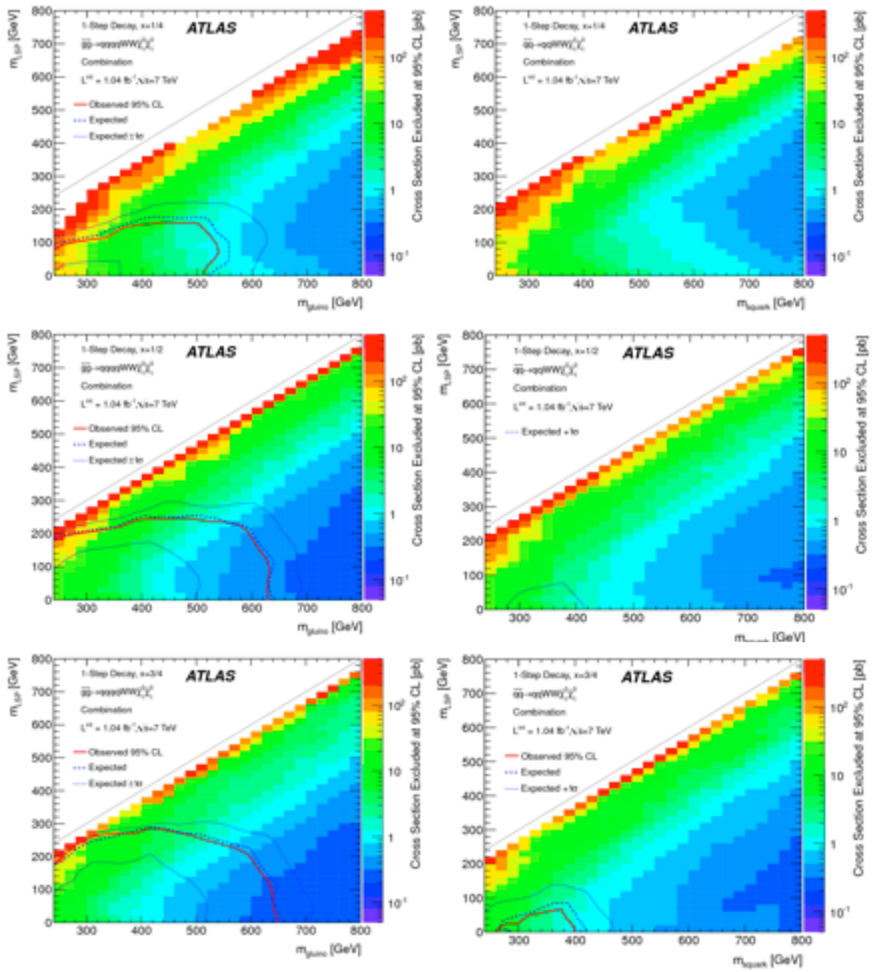
$m_{\tilde{g}} = m_{\tilde{q}} < 760 GeV$

1 lepton search interpretation

Simplified Model

Gluino model | Squark model

BR=100%



Consider: $\tilde{\chi}^{\pm} \rightarrow W^{(*)} \tilde{\chi}^{0}$

No $\tilde{b}$ $\tilde{t}$

Squark model ($\tilde{q}\tilde{q}$, $\tilde{q}\bar{\tilde{q}}$): $\tilde{q} \rightarrow q\tilde{\chi}^{\pm}$

Gluino model ($\tilde{g}\tilde{g}$): $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^{\pm}$

- 3 free parameters:

$$m_{\tilde{q}/\tilde{g}}, m_{\tilde{\chi}^{0}}$$

$$x = \left(m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}^{0}}\right) / \left(m_{\tilde{q}/\tilde{g}} - m_{\tilde{\chi}^{0}}\right)$$

Top: x=¼, lightest $\tilde{\chi}^{\pm}$

Middle: x=½

Bottom: x=¾ heaviest $\tilde{\chi}^{\pm}$

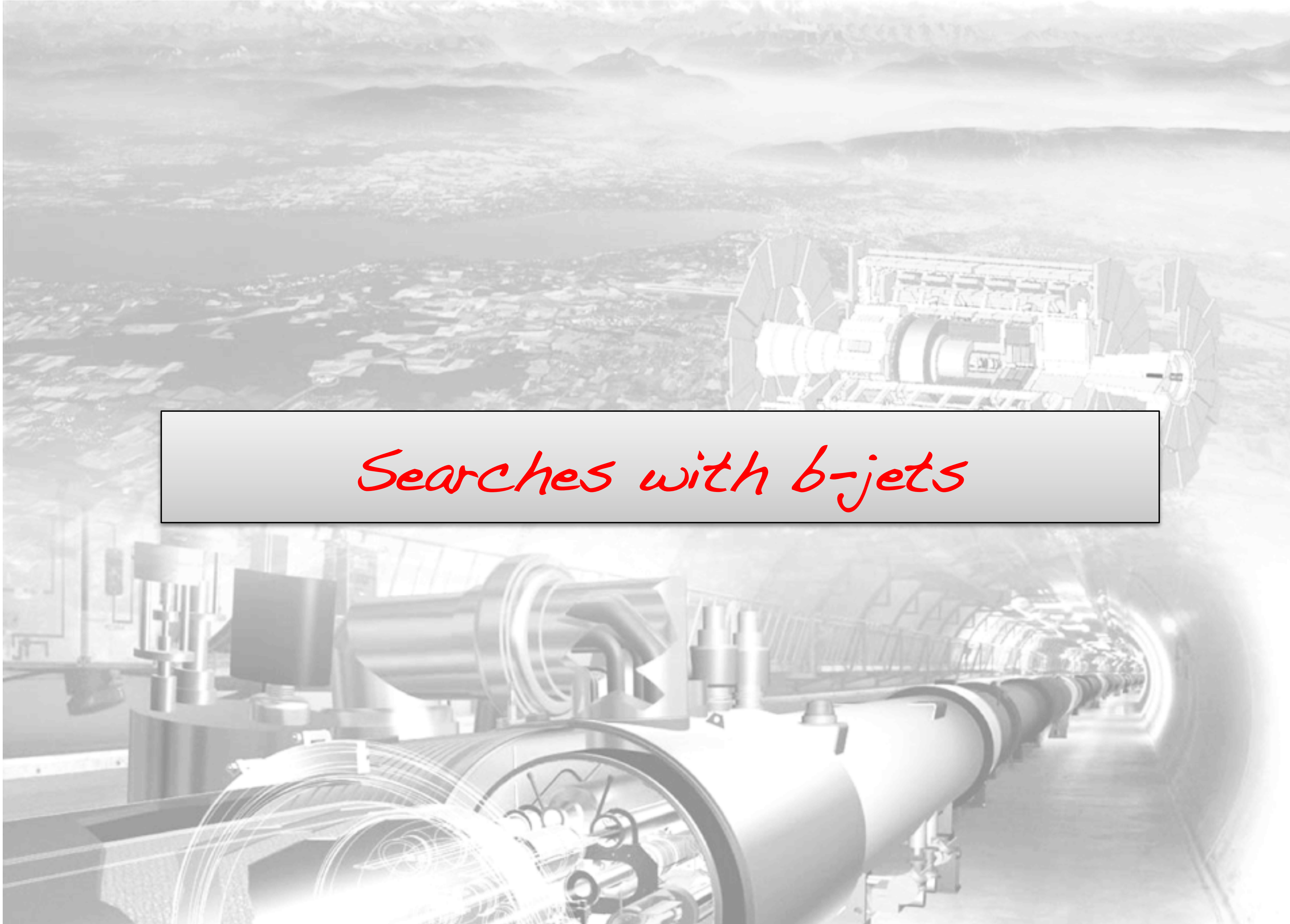
Colored map: cross-section limit

Full(dashed) lines: Observed(expected)

limits assuming MSSM cross section

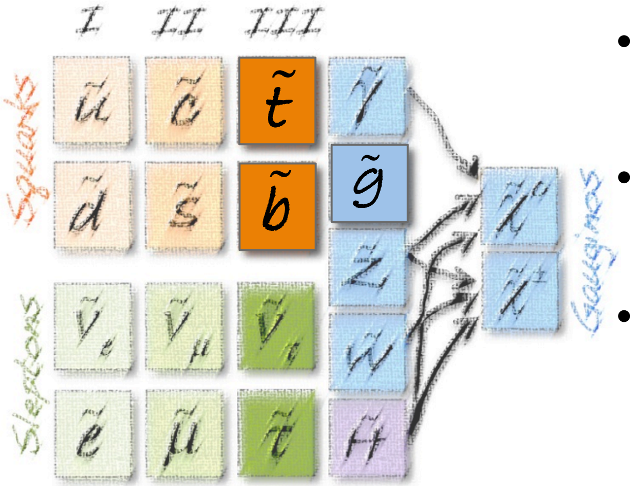
Gluino model has better reach due to SR with 4-jets

Limits deteriorate for compressed mass spectrum



Searches with b-jets

Searches with b-jets



- Mixing of $\tilde{q}_R$ and $\tilde{q}_L$ proportional to fermion masses: important for the 3rd generation
- Large mixing can yield to $\tilde{b}_1$ and $\tilde{t}_1$ being significantly lighter than other squarks
- Low stop mass also motivated by naturalness arguments:

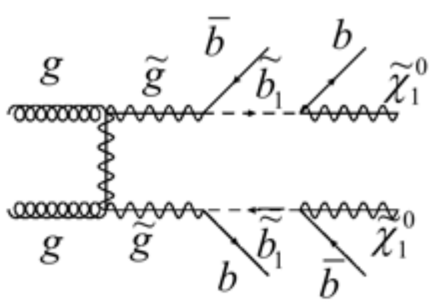
  $m_{\tilde{t}} < 500$ GeV to void too much fine tuning

Experimental search for direct stop, sbottom pair production or via gluino decay

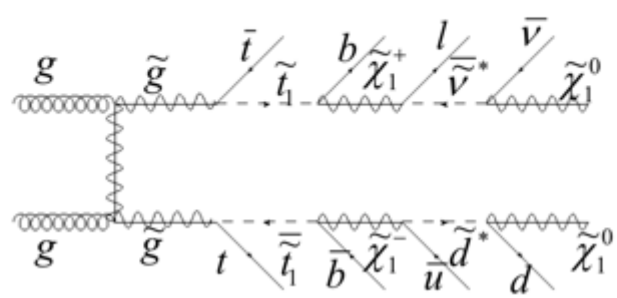
Gluino cross-section is larger:

preferred production @ LHC

$\tilde{g} \to \tilde{b}_1 b$



$\tilde{g} \to \tilde{t}_1 t$



<u>Experimentally challenging:</u>

- Small cross-section
- Difficult to disentangle from top
- Multiple decay scenarios to cover

$\tilde{g}$ mediated $\tilde{b}$ search

- Analysis selection similar to the 0-lepton analysis:
  - add the requirement of at least one b-jet p_T>50 GeV (displaced vertex algorithm)
- Event selection:
  - Jet p_T>130, 50, 50 GeV
  - $E_T$miss>130 GeV
  - $\Delta\varphi_{min}$>0.4 rad
  - $E_T$miss/m_{eff}>0.25

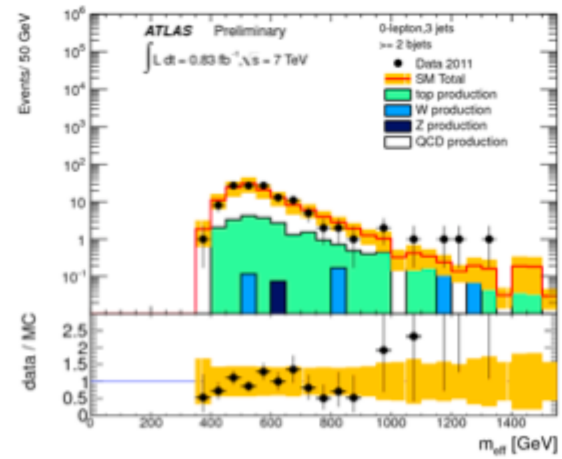
Trigger requirement (first two cuts)

To reduce QCD multijet (last two cuts)

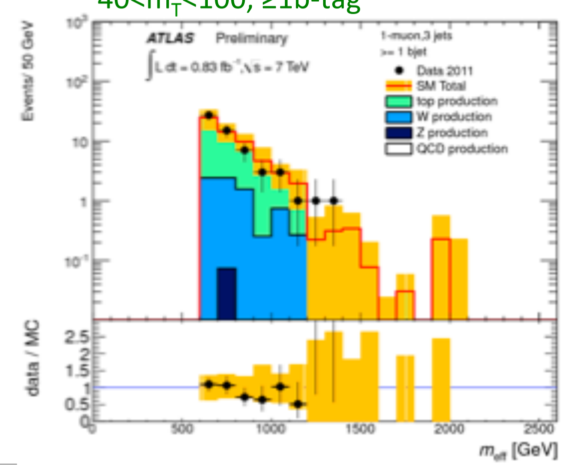
To maximize sensitivity define 4 signal regions

3J-A	3J-B	3J-C	3J-D
≥1 b-tag m_{eff}>500 GeV	≥1 b-tag M_{eff}>700 GeV	≥2 b-tag m_{eff}>500 GeV	≥2 b-tag M_{eff}>700 GeV

QCD CR: $\Delta\varphi_{min}$<0.4 rad

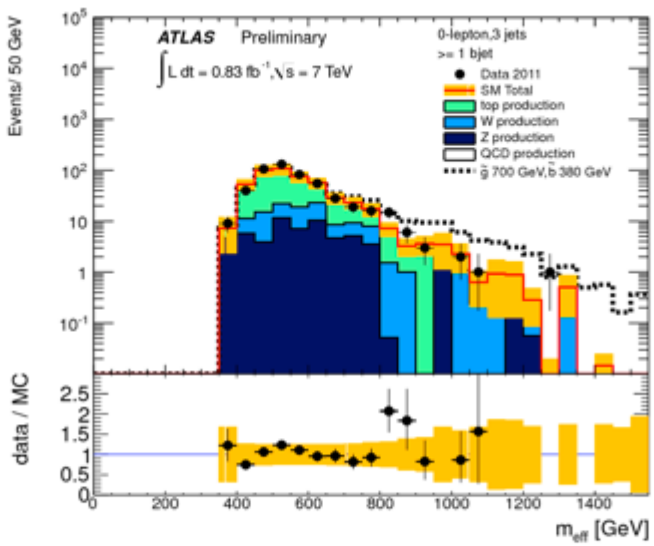


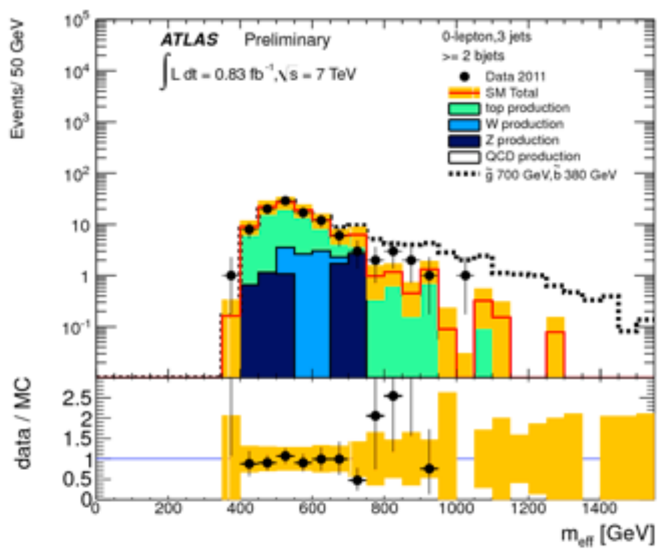
TopCR: 1 μ(e) p_T>20GeV, m_{eff}>600, 40<m_T<100, ≥1b-tag

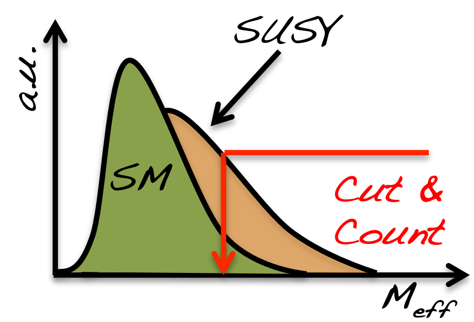


- Background estimate:
  - QCD multi-jet: same data-driven method as 0-lep
    - Smear jet momentum in low $E_T$miss data to generate "pseudo-events"
  - Top, W(bb), Z(bb) estimated using MC
    - Validation using data-driven estimate

$\tilde{g}$ mediated $\tilde{b}$ results







Main systematics uncertainties: top theory cross section (~30%), JES (~20%), b-tagging (1-20%)

Process	3J-A	3J-B	3J-C	3J-D
Total	356^{+103}_{-92}	70^{+24}_{-22}	79^{+28}_{-25}	$13^{+5.6}_{-5.2}$
Data	361	63	76	12

Model independent fiducial cross section limit, 95% C.L.

Signal Region	3J-A	3J-B	3J-C	3J-D
95% C.L N events	240	51	65	14
95% C.L σ (pb)	0.288	0.061	0.078	0.017

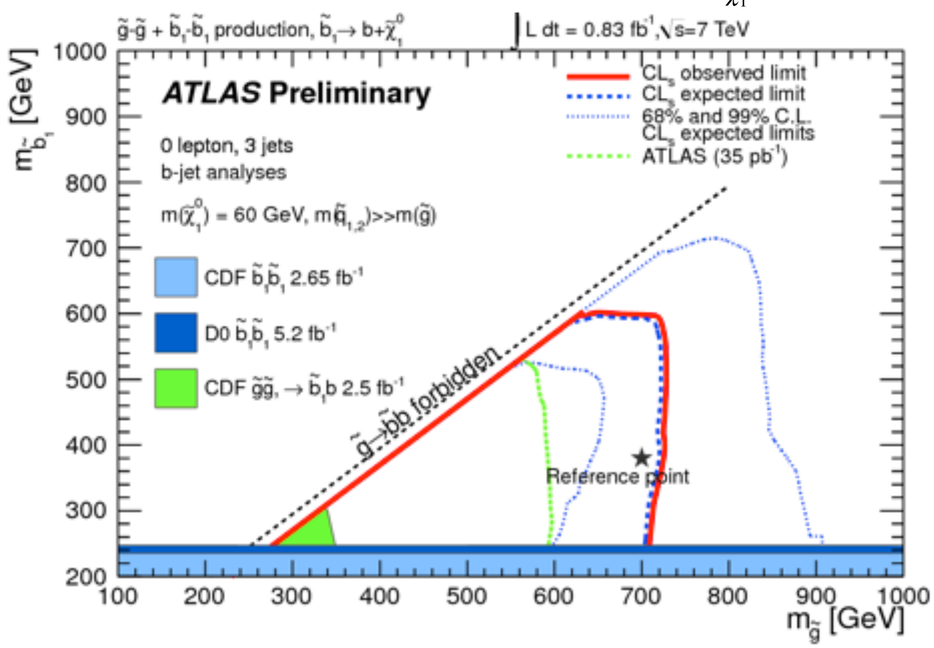
$\tilde{g}$ mediated $\tilde{b}$ interpretation

Best expected signal region per model point is chosen

Interpretation of the zero-lepton results in gluino-sbottom scenarios

Phenomenological MSSM

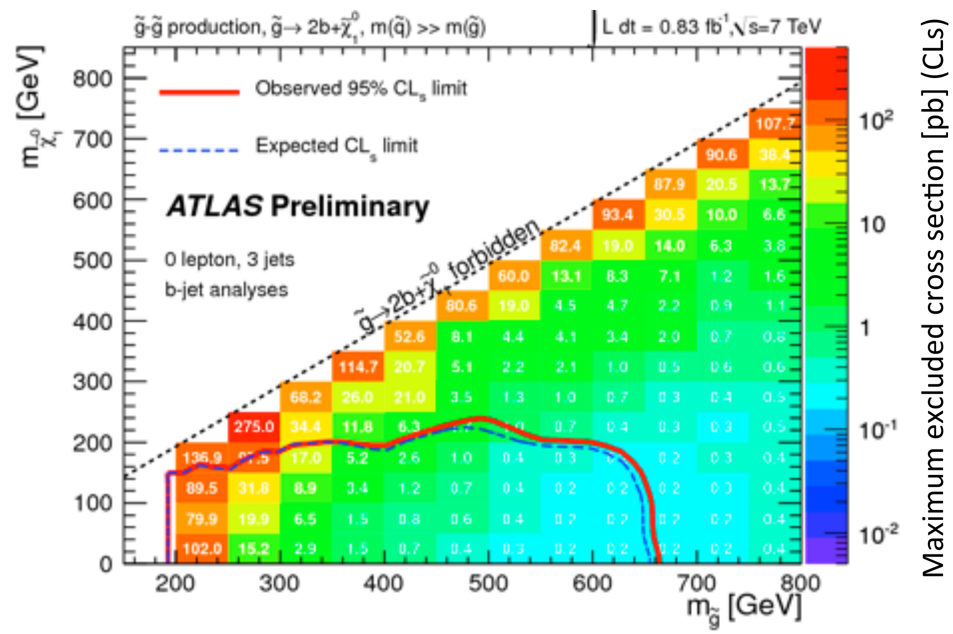
$BR(\tilde{g} \to \tilde{b}_1 b) = 100\%$ $BR(\tilde{b}_1 \to b + \tilde{\chi}_1^0) = 100\%$ $m_{\tilde{\chi}_1^0} = 60$ GeV



Gluino masses below 720 GeV excluded for sbottom masses below 600 GeV

General simplified model

Gluino-gluino production with 3-body decay to $\bar{b}b\tilde{\chi}_1^0$



Gluino masses between 200-660 GeV excluded up to LSP mass of 160 GeV

$\tilde{g}$ mediated $\tilde{t}$ search

- Searching for
  1) $\tilde{g} \to \tilde{t}t$
     - $\tilde{t} \to b\tilde{\chi}^{\pm}_1$
     - $\tilde{t} \to t\tilde{\chi}^{0}_1$
  2) $\tilde{g} \to t\bar{t}\chi^0_1$

Analysis selection similar to the 1-lepton analysis:

Event selection:

4 jets, 1 lepton(e,μ) and ≥1 b-jet

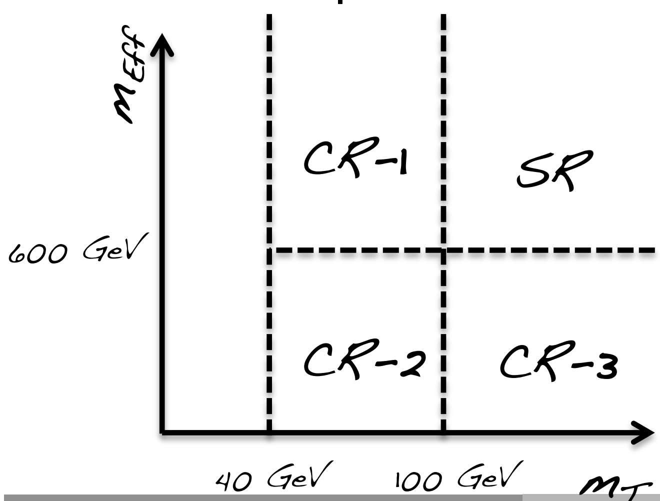
$E_T$miss >80 GeV

m_T>100 GeV

m_{eff}>600 GeV

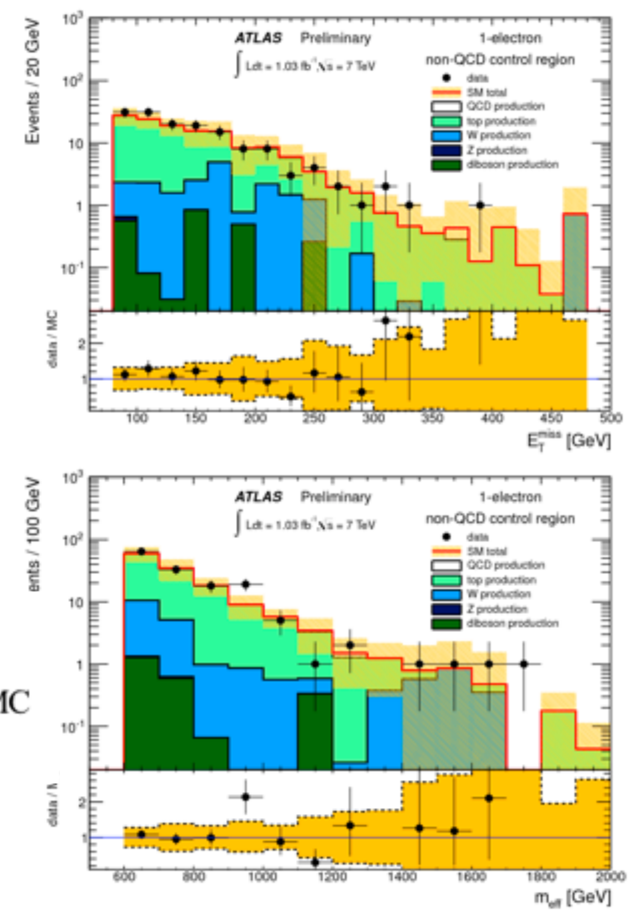
Background estimate:

- QCD multi-jet: same data-driven method as 1-lep
- Top & W/Zjets, CR region with same event selection apart for 40 GeV < m_T< 100 GeV

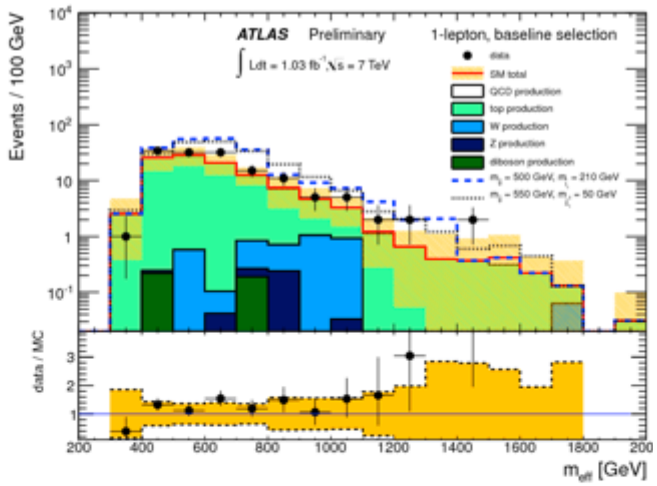


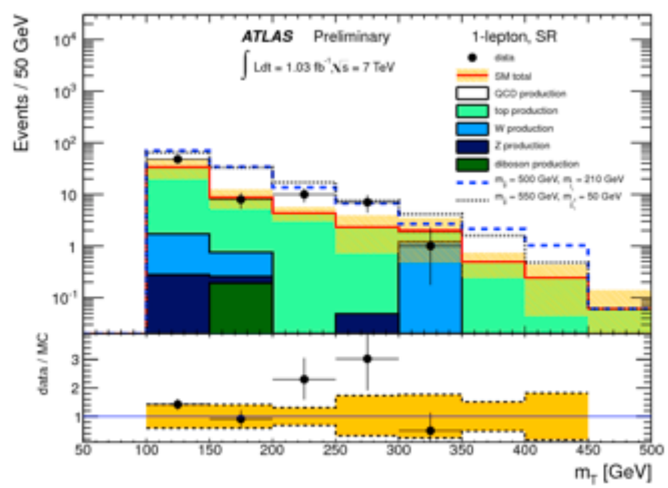
$$N^{SR}_{data} = N^{CR}_{data} \frac{N^{SR}_{MC}}{N^{CR}_{MC}} = N^{CR}_{data} T_{MC}$$

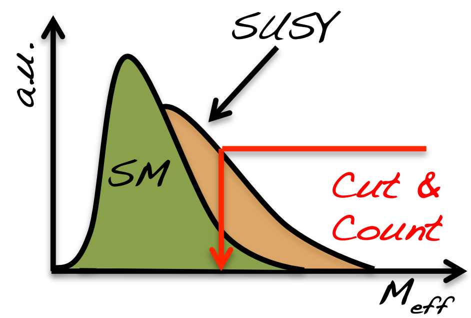
CR1 Electron channel



$\tilde{g}$ mediated $\tilde{t}$ result







	≥ 4 jets	≥ 1 b jets	ETmiss>80 GeV	Mt>100GeV	Meff>100 GEV (MC)	Meff>100 GeV (DD)
Total	6574±1870	3096±1042	881±356	109±55	52±28	**54.9±13.6**
Data	6659	3361	989	141	74	**74**

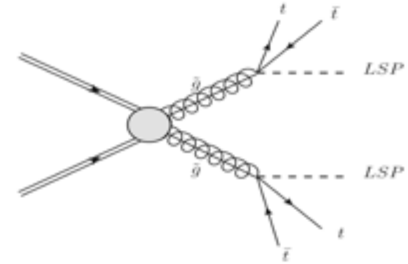
No significant deviation from SM expectation
(up fluctuation of 1.4σ)

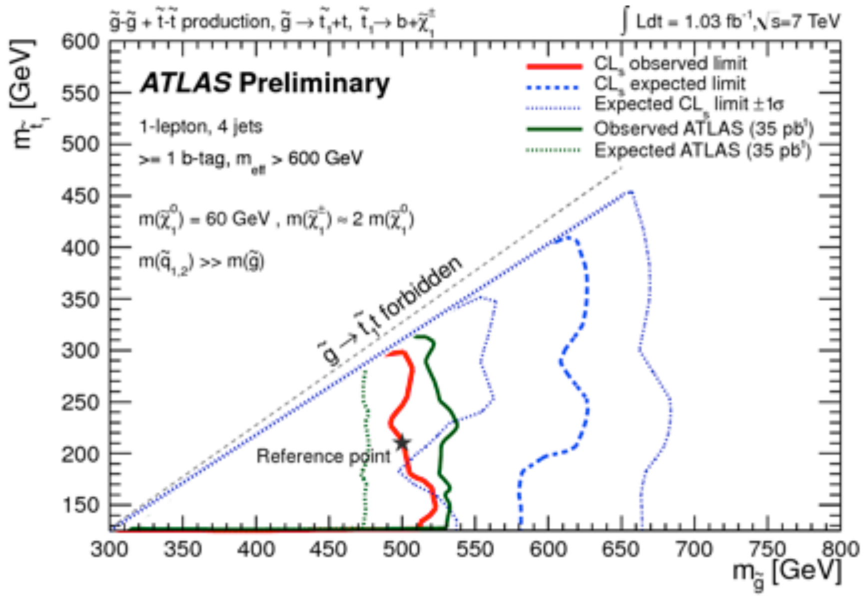
Model independent fiducial cross section limit, 95% C.L.

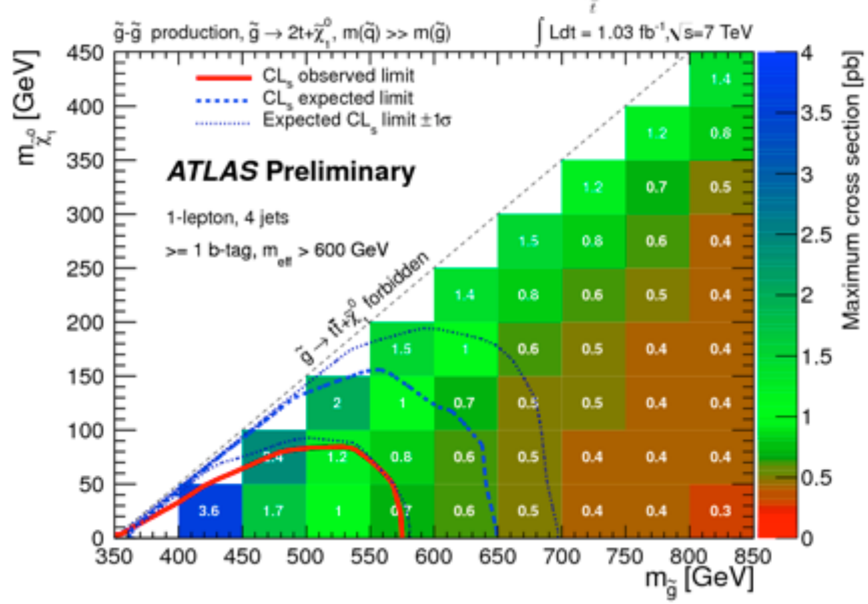
46 fb observed (31 fb expected)

1.03 fb^{-1}

$\tilde{g}$ mediated $\tilde{t}$ interpretation







Gluino-stop plane exclusion limit with $m_{\tilde{g}} > m_{\tilde{q}}$
The lightest neutralino mass is set to 60 GeV and the 2nd lighest chargino masses are 120GeV

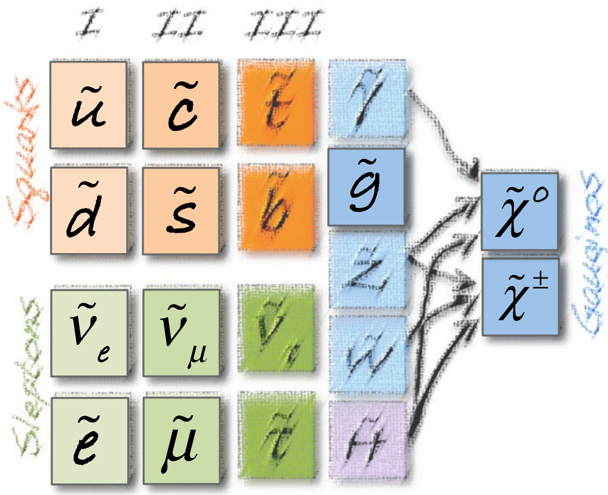
Gluino mass below 500 GeV is excluded

Gluino-neutralino plane exclusion limit in $\tilde{g} \rightarrow t\bar{t}\chi_1^o$ simplified model.

Gluino mass below 570 GeV is excluded (and up to LSP mass of 40 GeV)

dilepton searches

2-leptons search



Consider strong & weakino production

2 leptons from $\tilde{\chi}_i^0, \tilde{\chi}_i^\pm$ decays

a) $\tilde{\chi}_i^0 \to l^\pm \nu \tilde{\chi}_j^\mp$

b) $\tilde{\chi}_i^\pm \to l^\pm \nu \tilde{\chi}_j^0$

c) $\tilde{\chi}_i^0 \to l^\pm l^\mp \tilde{\chi}_j^0$

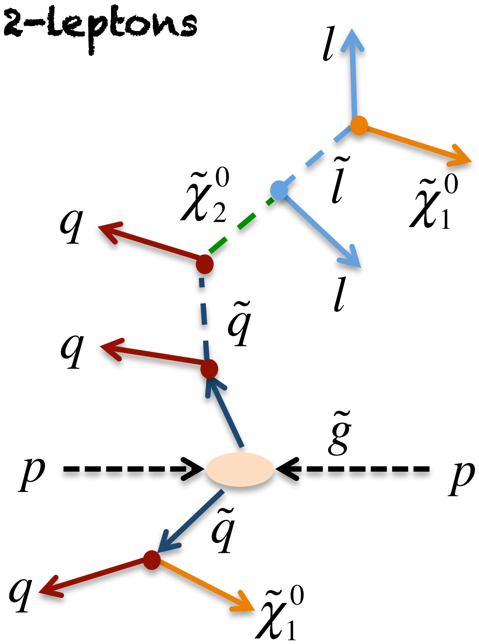
d) $\tilde{\chi}_i^\pm \to l^\pm l^\mp \tilde{\chi}_j^\pm$

<u>3 analyses:</u>

- Opposite sign (OS): a), b), c), d)
- Same sign (SS): a), b)
- Flavor subtraction (FS): c), d)

Different combinations exploited (e.g. OSSF)

2-leptons



<u>Event selection:</u>

2 isolated leptons & large $E_t$miss

ee: p_T 25,20
eμ: p_T 25,10
μe: p_T 20,20
μμ: p_T 20,10

Signal regions	OS-SR1	OS-SR2	OS-SR3	SS-SR1	SS-SR2	FS-SR1	FS-SR2	FS-SR3
$E_t$miss [GeV]	250	220	100	100	80	80	80	250
# jets		≥3	≥4		≥2		≥2	
Jet p_T [GeV]	✗	(80,40,40)	(100,70,70,70)	✗	(50,50)	✗	(20,20)	✗

Z veto

Backgrounds

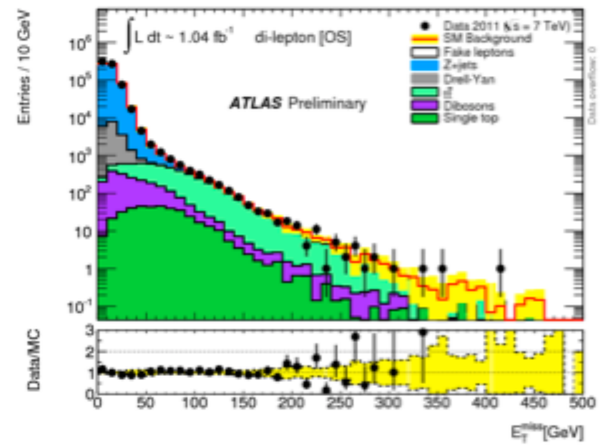
Big change in background composition and sensitivity between OS & SS

- Opposite sign
  - Top pair, Z+jets: normalize MC to data using CR. Extrapolate CR -> SR
    - Top: top-tag CR using m_{CT} (exploits the kinematics of top dilepton decay)

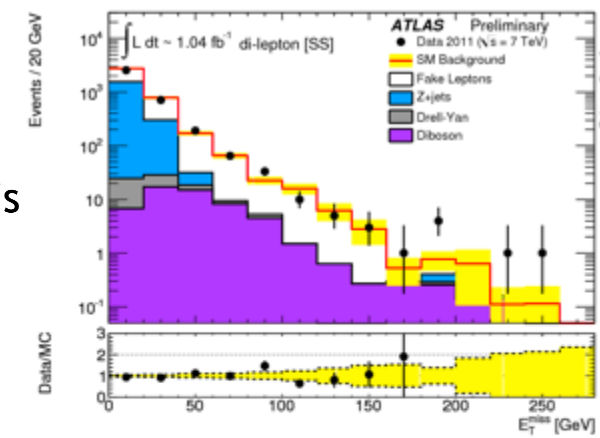
$$m_{CT}^2(v_1,v_2)=\left[E_T^{v_1}+E_T^{v_2}\right]^2-\left[\mathbf{p}_T^{v_1}+\mathbf{p}_T^{v_2}\right]^2$$

    - Z+jets: Z peak, low $E_T$miss
  - Diboson, single top: from MC

No jet requirement

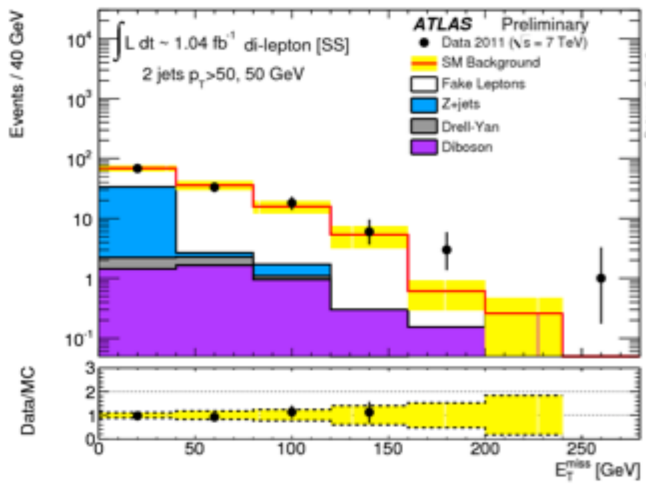


- Same sign
  - Fake lepton: data-driven matrix method
    - Extension of the method used for the 1-lepton analysis
  - Charge flip (e.g. trident): measured from MC Zee, apply to top MC
  - Diboson: from MC

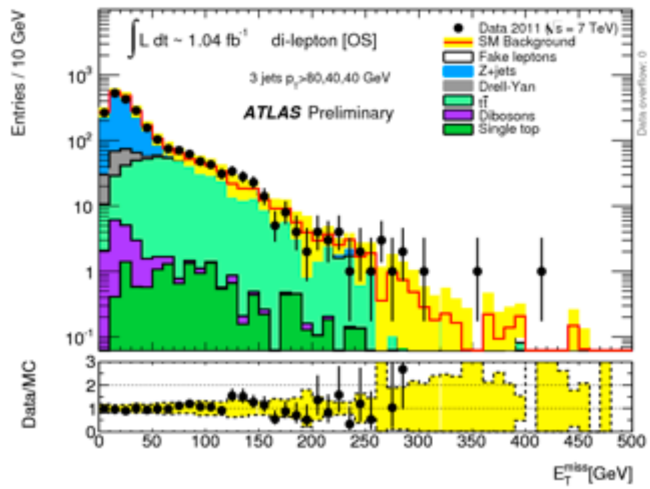


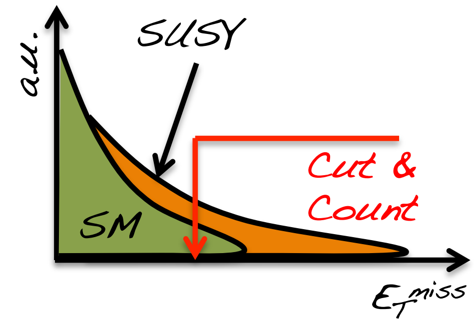
2-leptons search results

SS ≥2jets



OS ≥3jets





Model independent fiducial cross section upper limit, 95% C.L.

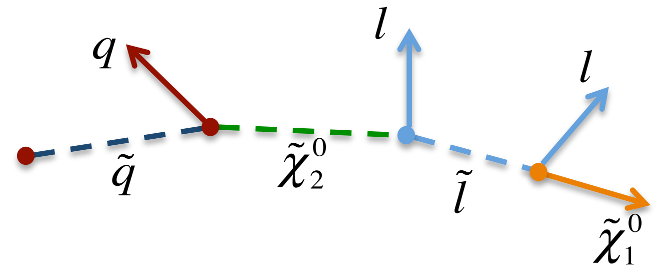
	Background	Data	95% C.L.
OS-SR1	15.5 ± 1.2 ± 4.4	13	9.5 fb
OS-SR2	13.0 ± 1.8 ± 4.1	17	15.2 fb
OS-SR3	5.7 ± 1.1 ± 3.5	2	5.0 fb
SS-SR1	32.6 ± 4.4 ± 4.4	25	10.2 fb
SS-SR2	24.9 ± 4.1 ± 6.6	28	20.3 fb

Flavor subtraction result

- Use OS events to search for excess OS same flavor events.
  - These decay chains offer one of the best routes to measure SUSY masses via edges in flavor subtracted m_{ll}

 Flavor "symmetric" backgrounds like top dilepton cancel.

$$\tilde{\chi}_2^0 \to \tilde{l}^{\pm} l^{\mp} \to \tilde{\chi}_1^0 l^+ l^-$$



Quantify consistency with:

$$S = \frac{N(e^{\pm}e^{\mp})}{\beta\left(1-(1-\tau_e)^2\right)} + \frac{\beta N(\mu^{\pm}\mu^{\mp})}{1-(1-\tau_{\mu})^2} - \frac{N(e^{\pm}\mu^{\mp})}{1-(1-\tau_e)(1-\tau_{\mu})}$$

B: ratio of e/μ reco efficiencies/acceptance

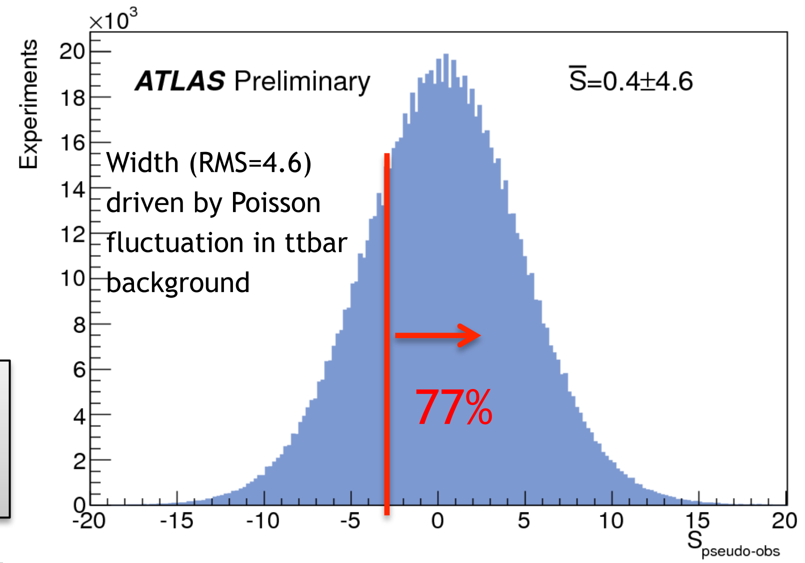
τ : trigger efficiencies

Most stringent limit set for FS-SR3

$$S_{obv} = -3.1 \pm 0.003\ (sys)$$

$$\bar{S}_b = 0.4 \pm 1.2 \pm 1.2$$

77% of the experiment have $S>S_{obs}$



Assuming for SUSY $e^{\pm}e^{\mp} = \mu^{\pm}\mu^{\mp}$ and $e^{\pm}\mu^{\mp} = 0$

Limit on $\bar{S}_s < 4.9$ at 95% C.L.

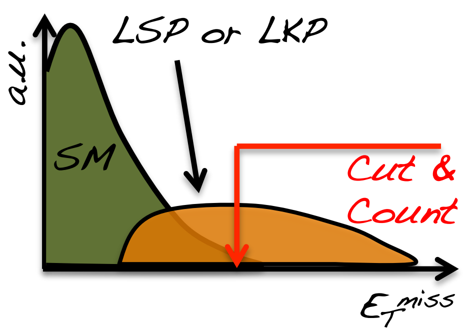
Diphoton searches

1.07 fb^{-1} Inclusive search with 2 γ and E_T^{miss}

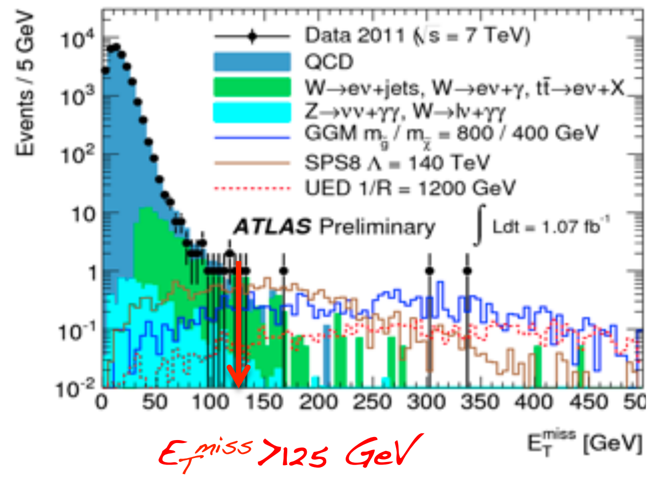
Sensitive to gauge-mediated SUSY breaking and UED models

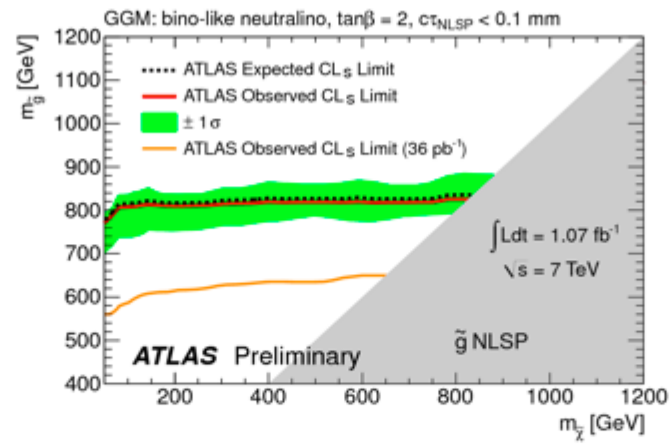
- In GMSB SUSY (SUSY breaking is gauge-mediated), the LSP is the gravitino, $\tilde{G}$
  - Final decay in the cascade is dominated by $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$, with 2 cascade per event
  - Signature: 2 γ & E_t^{miss}
- Similar topologies are generated in Universal Extra Dimension (UED)

  The lightest KK particle (LKP) is the Kaluza-Klein photon



Expected background: 4.1 ± 0.6 ±
5 observed





95 % C.L upper limit: σ<0.02-0.04 pb in GGM model

$m_{\tilde{\chi}_1^0} = 150\ GeV,\ m_{\tilde{g}} = 400 - 1200\ GeV$

Exclude GGM gluino mass<776 GeV, $m_{\tilde{\chi}_1^0} > 50$ GeV

SP8 breaking scale Λ<145TeV

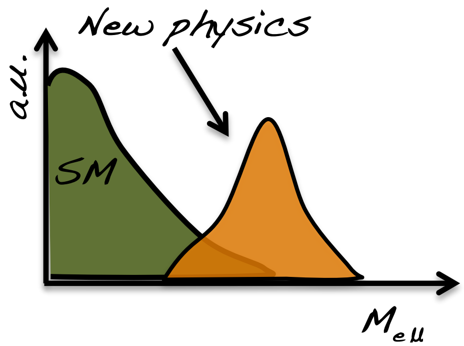
UED compactification radius: $1/R_{UED}$<1224 GeV

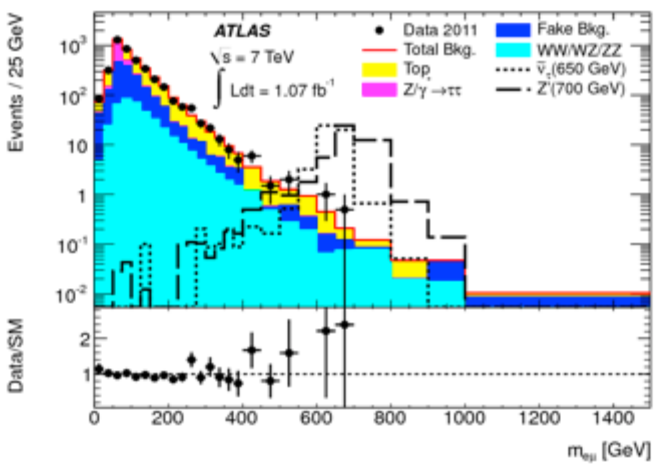
RPV dedicated search

e+μ resonance search

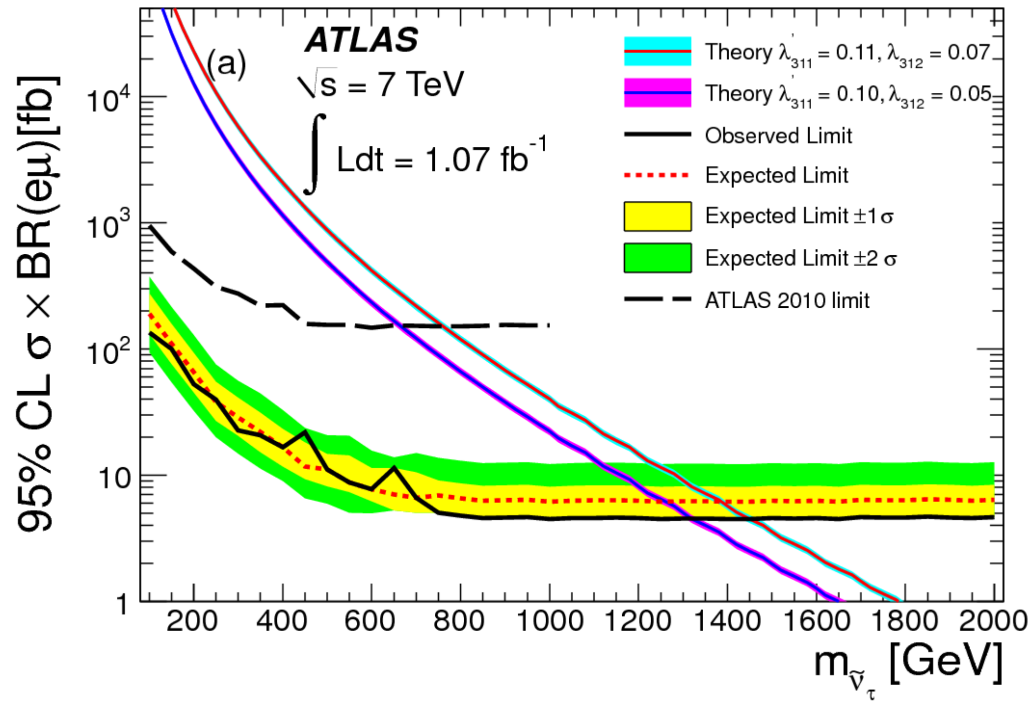
e.g. R-parity violating $d\bar{d} \xrightarrow[\lambda'_{311}]{} \tilde{\nu}_\tau \xrightarrow[\lambda_{321}]{} e\mu$

- Single sparticle, Lepton Flavor Violation (LVF), no E_T^{miss}
  - Also sensitive to models with LVF decays of an extra gauge boson: Z'
- Lepton requirement: p_T>25 GeV & isolation





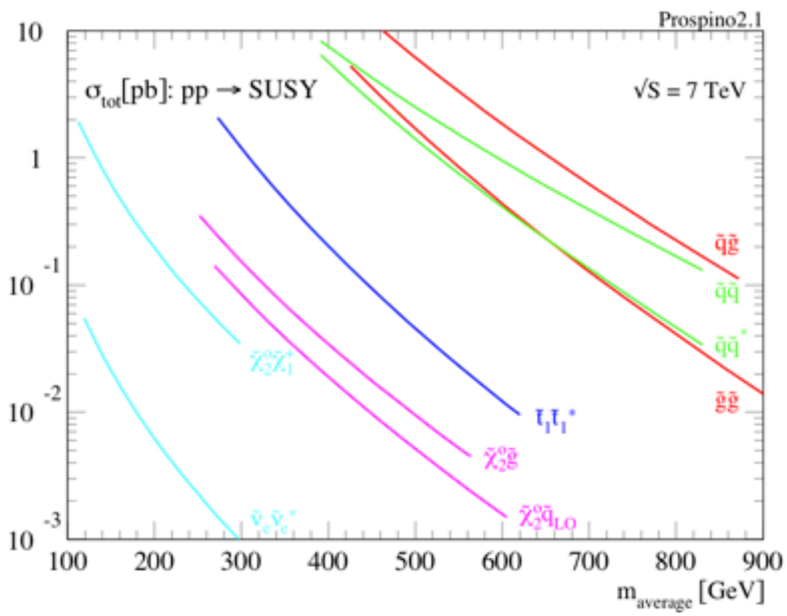
SM expectation: 4150±250
Observe: 4053



Limits on RPV coupling at 95 % C.L exclude $m_{\tilde{\nu}_\tau} < 1.45\ TeV$ for λ'_{311}=0.01, λ_{312}=0.07

Outlook

- Excluding simplest SUSY scenarios for masses ~600-1000 GeV
- Effort in interpreting results via simplified/pheno models



<u>Strong production:</u>

Well explore for large mass splitting

New channels:

- Compressed spectra
- Long decay chains
- RPV signatures (resonances)

<u>Stop/Sbottom pair productions:</u>

- Gain wrt Tevatron
- Extremely challenging (small σ, large top bkg)

<u>Direct gaugino production:</u>

- Relevant when colored spartners are too heavy
- Good sensitivity in multilepton channels

Cover new signatures

Improving existing analyses:

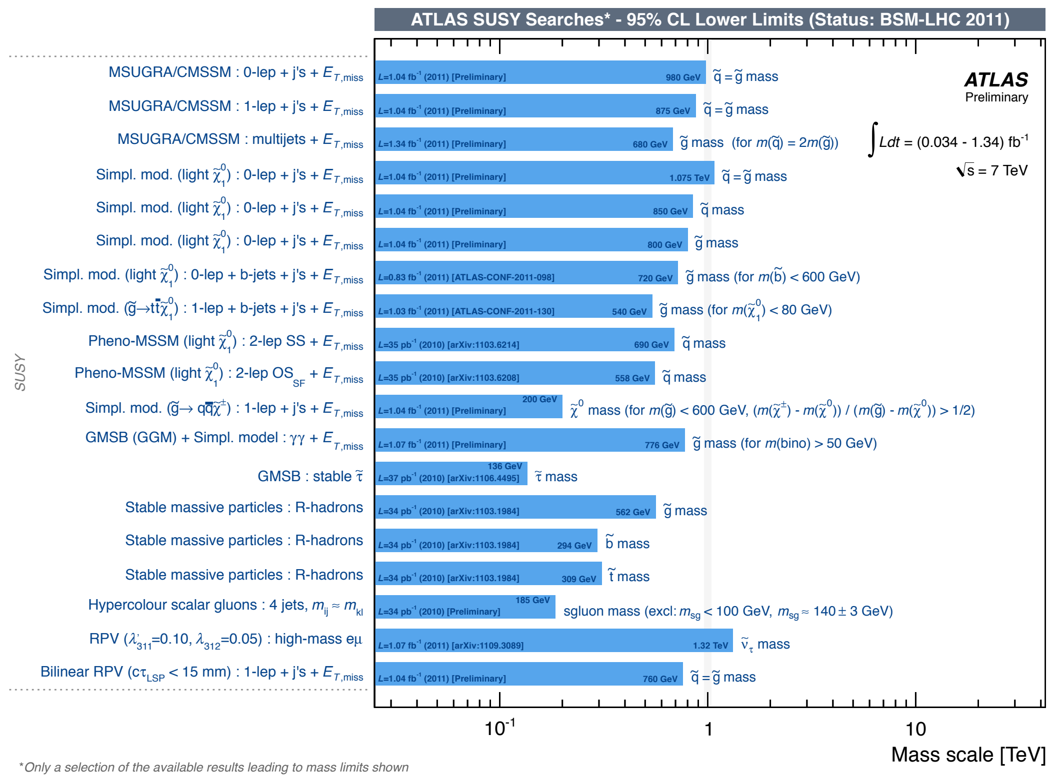
Systematics uncertainties (e.g. JES, MC statistics), softer leptons, object performance…

Use shape (e.g. $E_T$miss, m_{Eff})

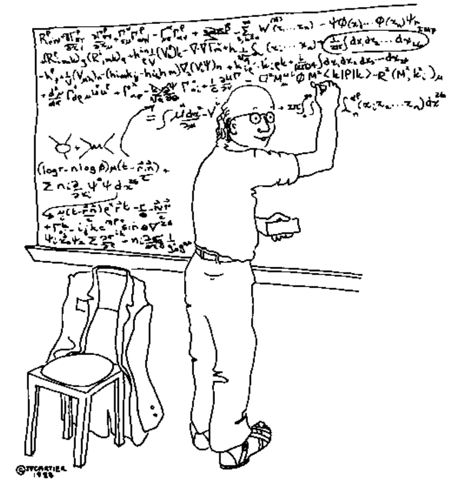
Conclusions

SUSY was NOT "just around the corner"

… must be hiding well …



Or may be … need to go back to the drawing board



"At this point we notice that this equation is beautifully simplified if we assume that space-time has 92 dimensions."

More data on tape… more ideas to cover different final states, refined techniques

The search has not finished yet. In some cases, it's just starting…

ATLAS Latest SUSY Results

ATLAS SUSY analyses	Publications
E_T^{miss} + Jets + 0 lepton Large multiplicity	arXiv:1109.6572 (1.1 fb^{-1}) [submitted to PLB] arXiv:1110.2299 (1.3 fb^{-1}) [submitted to JHEP];
E_T^{miss} + Jets + 1 lepton	arXiv:1109.6606 (1.1fb^{-1}) [published in PRD];
E_T^{miss} + b Jets + 0 lepton E_T^{miss} + b Jets + 1 lepton	ATLAS-CONF-2011-198 (0.83 fb^{-1}) ATLAS-CONF-2011-130 (1.03 fb^{-1})
E_T^{miss} + Jets + 2 leptons (OS, SS, SF subtraction)	arXiv:XXXX.XXXX (1.04 fb^{-1}) [to be submitted]
E_T^{miss} + Jets + >= 3 leptons	ATL-CONF-2011-039 (34 pb^{-1})
E_T^{miss} +γγ	arXiv:XXXX.XXXX (1.07 fb^{-1}) [to be submitted]
eμ resonance (RPV)	arXiv:1109.3089 (1.07 fb^{-1}) [submitted to EPJCL];
Displaced vertices of new heavy particles	arXiv:1109.2242 (33pb^{-1}) [submitted to PLB]
Massive color scalar	arXiv:1110.2693 (33pb^{-1}) [submitted to EPJC]
Stable hadronising squarks & gluinos	PLB 701 (2011) 1
Heavy Long-lived charged particles	PLB 703 (2011) 428