SUSY and high-p_T flavor tagging at ATLAS

Flavor Physics and CP Violation 2011
Kibbutz Maale Hachamisha, Israel

May 2011

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On behalf of the ATLAS Collaboration

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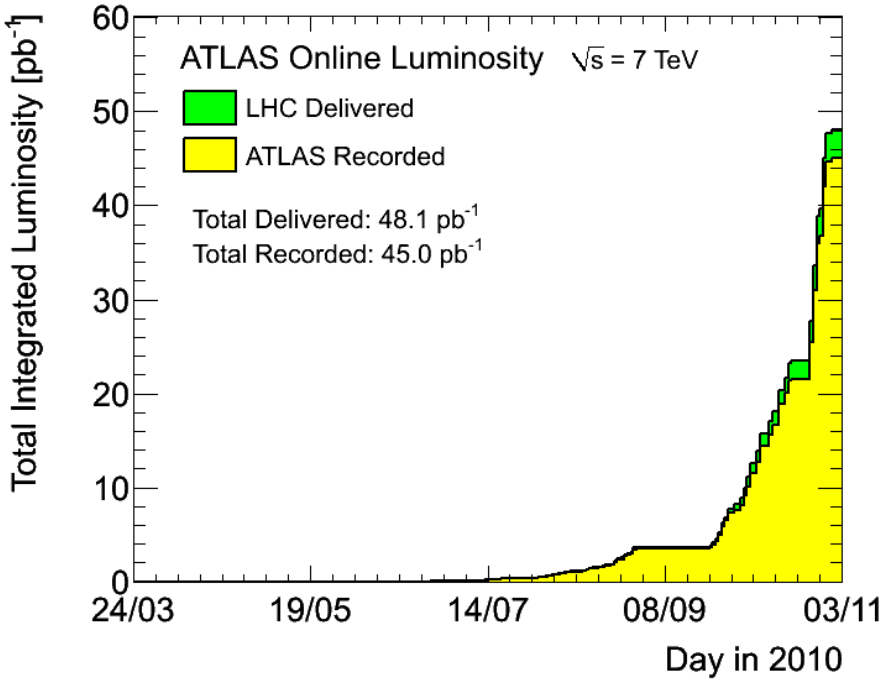
ATLAS 2010-2011

In 2010 ATLAS recorded 45 pb^{-1} data

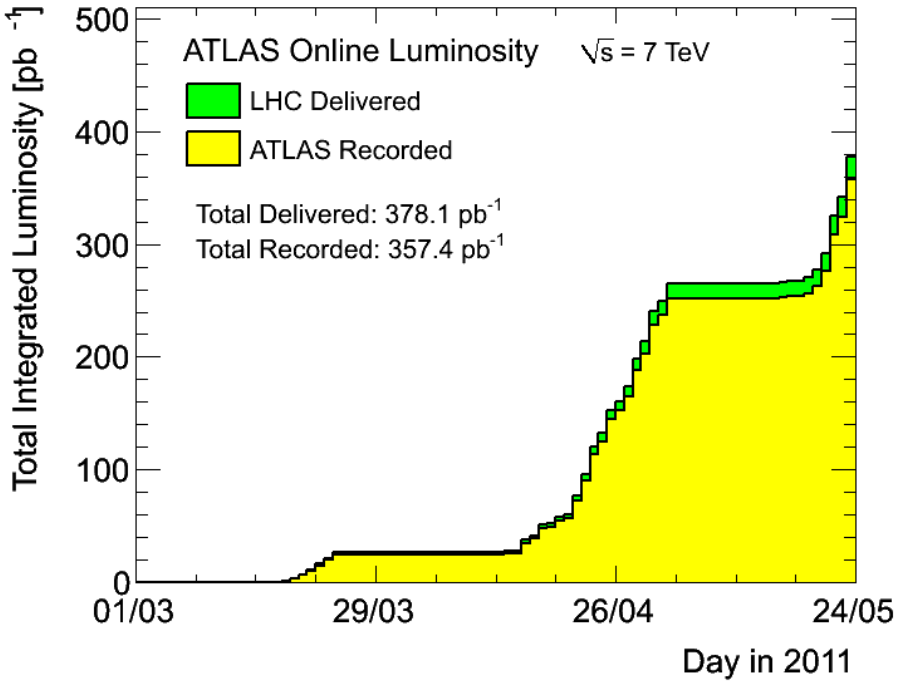
<u>This talk will focus on the 2010 data results</u>

35 pb^{-1} after ATLAS detector is required to be fully operational



In 2011 ATLAS has already recorded ~350 pb^{-1} data

Updates to analyses expected very soon



SUSY Search Strategy

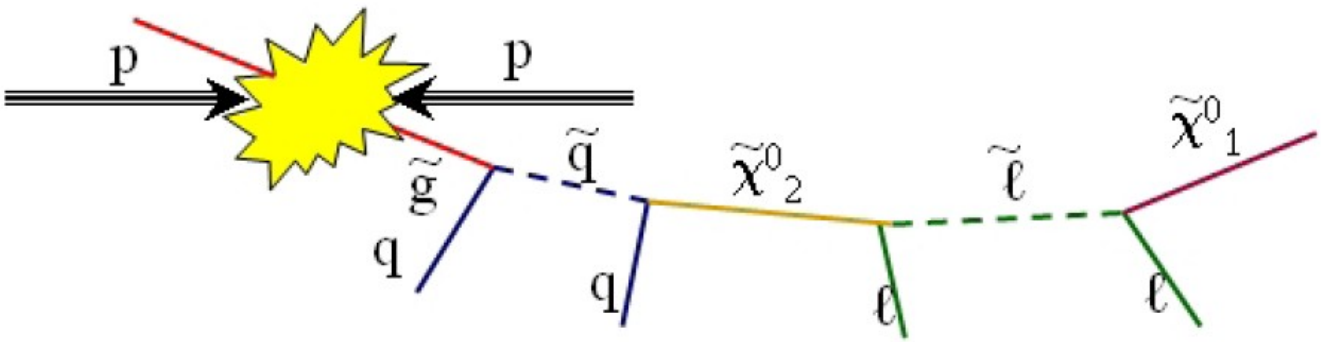
SUSY offers a rich array of signatures!

Long decay chains through gluinos, squarks, gauginos and sleptons.

ATLAS aims to search for SUSY in a model-independent way

R-Parity conserving models discussed here

The lightest SUSY particle (LSP) is stable and escapes detection
→ **Missing Transverse Energy**



Decaying colored sparticles produce **jets**

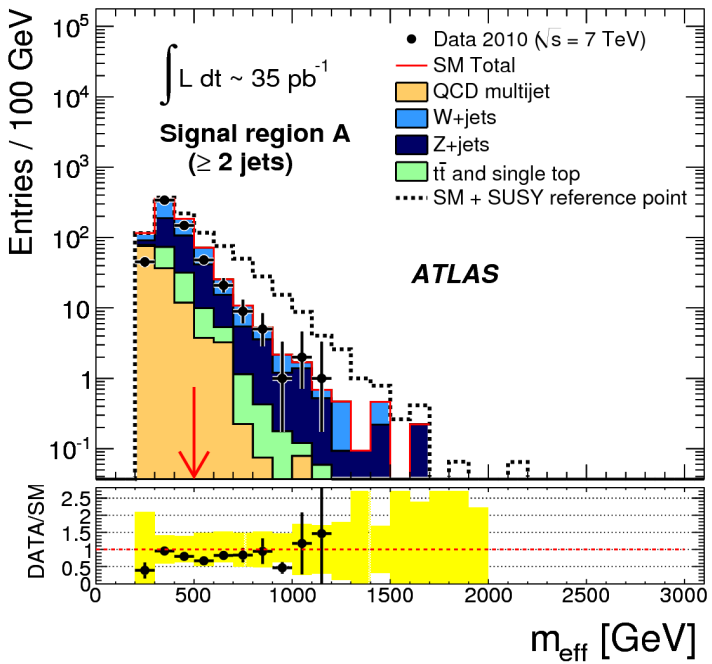
Decaying sleptons and gauginos can produces **leptons**

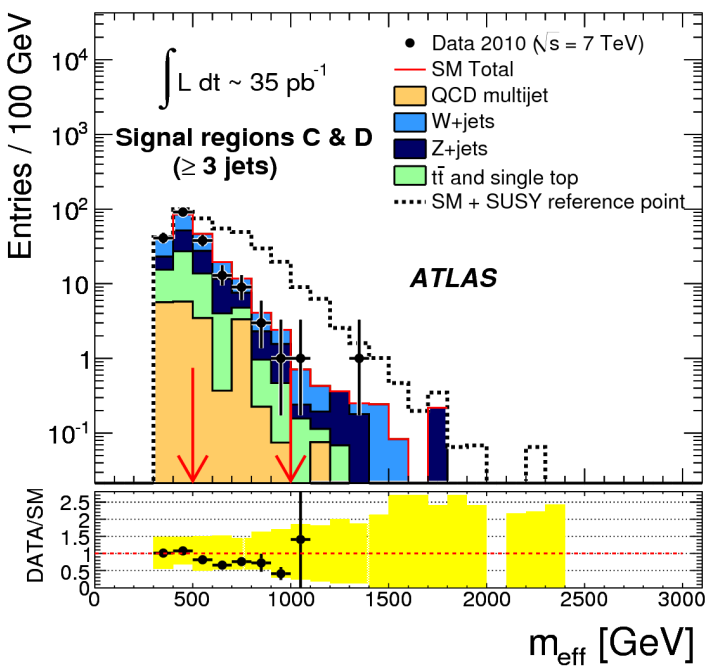
3rd generation may be kinematically favoured
→ **b-jet, tau** signatures

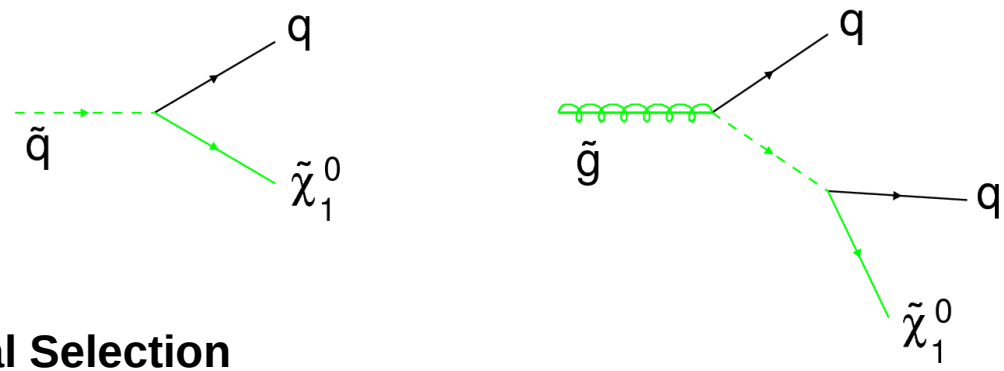
0-lepton channel

$\int L\,dt \sim 35\ pb^{-1}$

arXiv:1102.5290 submitted to PLB







Signal Selection

A: light-$\tilde{q}\,\tilde{q}$
B: heavy-$\tilde{q}\,\tilde{q}$
} 1 jet per squark

C: $\tilde{g}\,\tilde{g}$
D: $\tilde{g}\,\tilde{q}$
} Extra jets from gluino decay

		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

$$m_{eff} = E_T^{miss} + p_T^{lep} + \sum_0^3 p_T^{jet\ i}$$

m_{T2} = maximal lower bound on the mass of a pair produced particle which decays into one of the pre-selected jets and a massless undetected particle, assuming the two undetected particles are the only source of p_T^{miss}

0-lepton channel backgrounds

$\int L\,dt \sim 35\ pb^{-1}$

Mainly W+jets, Z+jets. top quark pairs, QCD multijets and single top

<u>MC estimate</u>

W+jets: leptonic decay where no lepton is reconstructed.
$W \rightarrow \tau\nu$ + jets is a significant component

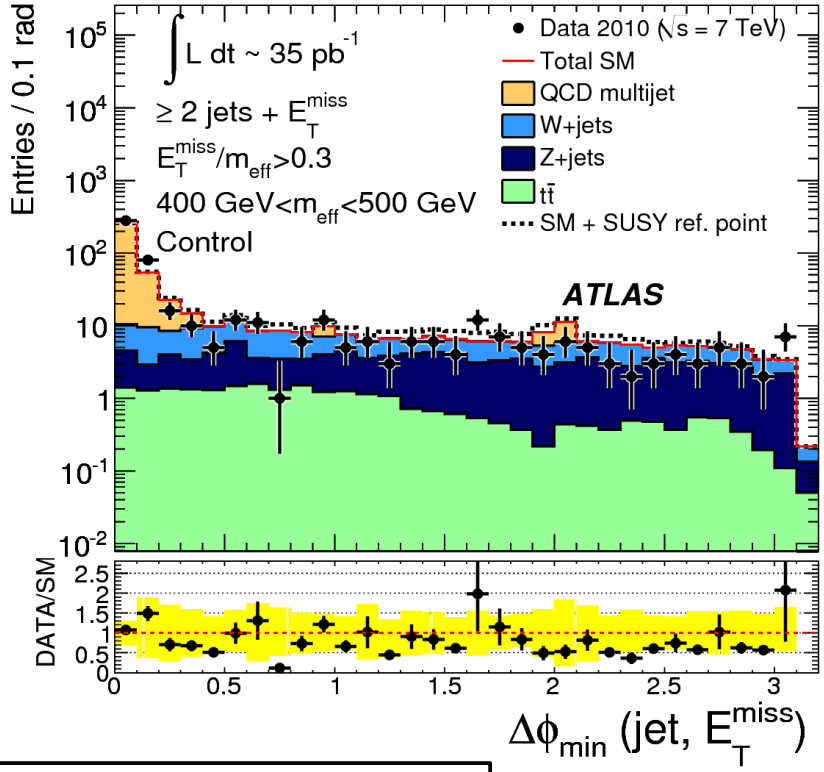
Z+jets: decay to neutrinos → large E_T^{miss}

Top: mainly hadronic τ decay + jets

<u>Normalised to data in control regions</u>

QCD multijets: poorly reconstructed jets → fake E_t^{miss}

low $\Delta\varphi(jet, E_T^{miss})$ control region + jet and m_{eff} cuts to minimise QCD theory uncertainty in extrapolation



Cross-checks

W/Z consistent with
- "tau-embedding": re-simulation of reconstructed leptons as hadronically decaying taus ($W \rightarrow \tau\nu$ + jets)
- removal of leptons from W(l)+jet and Z(ll)+jet events
- comparing MC predictions to data in control regions enriched with background events

Top constitent with
- data-driven method replacing reconstructed muons in single lepton channels with simulated hadronic decays.
- reweighting the top MC according to experimentally measured b-tag weights.

QCD multijets consistent with
- data-driven method smearing jets in low-E_T^{miss} data events to generate high-E_T^{miss} events
- additional control regions with reversed E_T^{miss}/m_{eff} requirements to checks normalisation.

0-lepton results

$\int L\,dt \sim 35\ pb^{-1}$

	Signal region A	Signal region B	Signal region C	Signal region D
QCD	$7\ ^{+8}_{-7}$[u+j]	$0.6\ ^{+0.7}_{-0.6}$[u+j]	$9\ ^{+10}_{-9}$[u+j]	$0.2\ ^{+0.4}_{-0.2}$[u+j]
W+jets	50 ± 11[u] $^{+14}_{-10}$[j] $\pm$ 5[$\mathcal{L}$]	4.4 ± 3.2[u] $^{+1.5}_{-0.8}$[j] ± 0.5[$\mathcal{L}$]	35 ± 9[u] $^{+10}_{-8}$[j] $\pm$ 4[$\mathcal{L}$]	1.1 ± 0.7[u] $^{+0.2}_{-0.3}$[j] ± 0.1[$\mathcal{L}$]
Z+jets	52 ± 21[u] $^{+15}_{-11}$[j] $\pm$ 6[$\mathcal{L}$]	4.1 ± 2.9[u] $^{+2.1}_{-0.8}$[j] ± 0.5[$\mathcal{L}$]	27 ± 12[u] $^{+10}_{-6}$[j] $\pm$ 3[$\mathcal{L}$]	0.8 ± 0.7[u] $^{+0.6}_{-0.0}$[j] ± 0.1[$\mathcal{L}$]
$t\bar{t}$ and t	10 ± 0[u] $^{+3}_{-2}$[j] $\pm$ 1[$\mathcal{L}$]	0.9 ± 0.1[u] $^{+0.4}_{-0.3}$[j] ± 0.1[$\mathcal{L}$]	17 ± 1[u] $^{+6}_{-4}$[j] $\pm$ 2[$\mathcal{L}$]	0.3 ± 0.1[u] $^{+0.2}_{-0.1}$[j] ± 0.0[$\mathcal{L}$]
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] $\pm$ 12[$\mathcal{L}$]	10.0 ± 4.3[u] $^{+4.0}_{-1.9}$[j] ± 1.0[$\mathcal{L}$]	88 ± 18[u] $^{+26}_{-18}$[j] $\pm$ 9[$\mathcal{L}$]	2.5 ± 1.0[u] $^{+1.0}_{-0.4}$[j] ± 0.2[$\mathcal{L}$]
Data	87	11	66	2

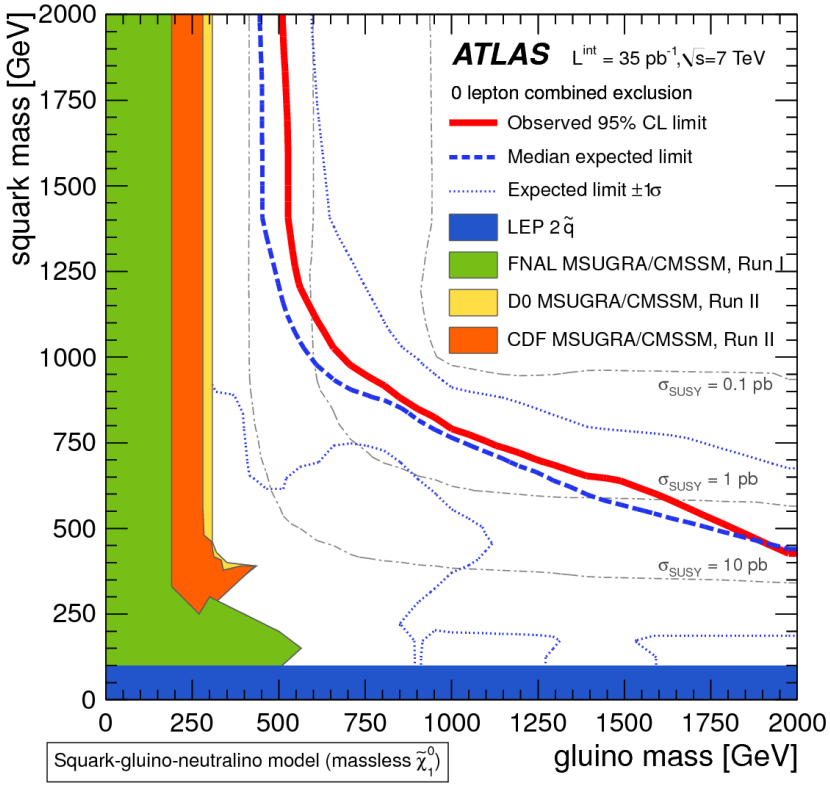
Uncertainties
[u] stat. + uncorrelated syst.
[j] jet energy scale
[L] luminosity

Profile likelihood used to set a 95% CL upper limit on the effective σ
1.3 pb (A), 0.35 pb (B), 1.1 pb (C), 0.11 pb (D)

effective σ = σ xBR x acceptance

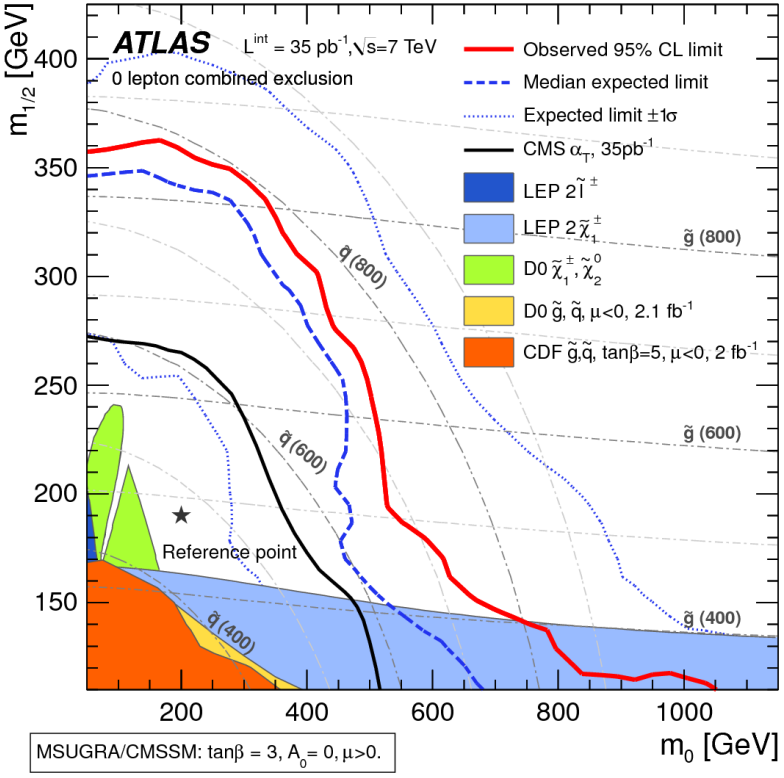
Simplified Model framework

$m(\tilde{g}) < 500$ GeV excluded at 95% CL
$m(\tilde{g}) = m(\tilde{q}) < 870$ GeV excluded at 95% CL



mSUGRA/CMSSM framework

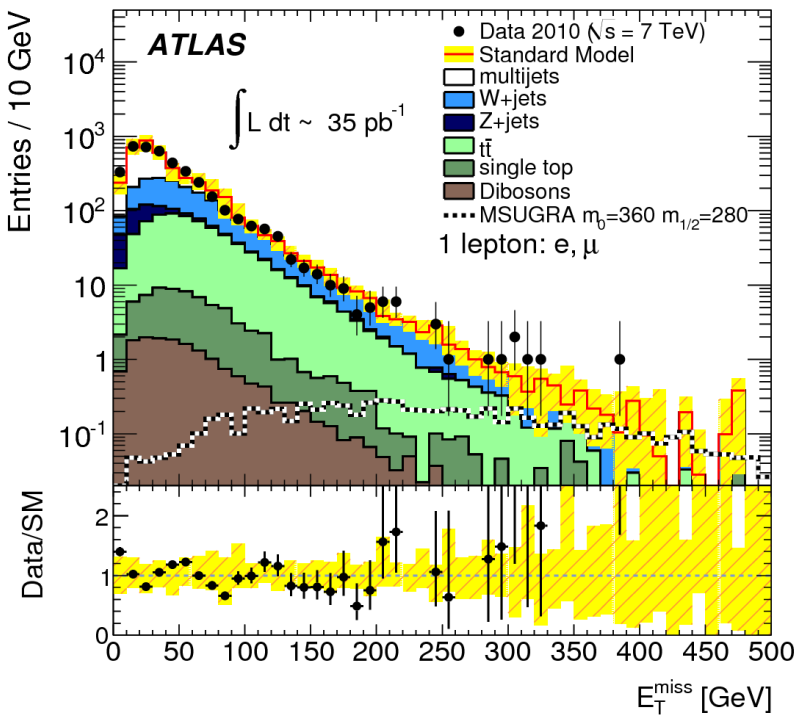
$m(\tilde{g}) = m(\tilde{q}) < 775$ GeV excluded at 95% CL

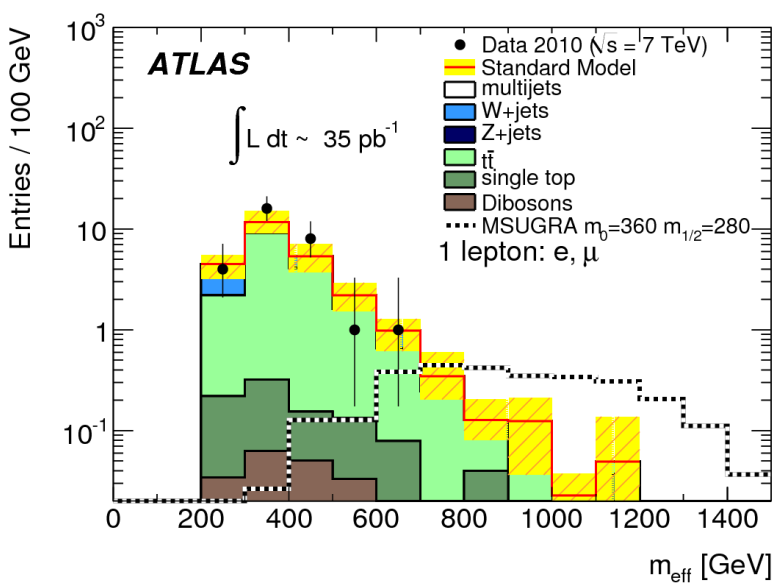


1-lepton channel

$\int L\,dt \sim 35\ pb^{-1}$

Phys. Rev. Lett. 106, 131802 (2011) arXiv:1102.2357





$$\tilde{q}_L \to q\,\tilde{\chi}^{\pm} \to q\,l^{\pm}\,\nu\,\tilde{\chi}_1^0$$
$$\tilde{g} \to q\,\bar{q}'\,\tilde{\chi}^{\pm} \to q\,\bar{q}'\,l^{\pm}\,\nu\,\tilde{\chi}_1^0$$

Signal Selection

Exactly 1 lepton $p_T > 20$ GeV

At least 3 jets $p_T > 60,\ 30,\ 30$ GeV

$\Delta\phi(\text{jet}_i, E_T^{miss}) > 0.2\ (i = 1,2,3)$

$m_T > 100$ GeV

$E_T^{miss} > 125$ GeV

$E_T^{miss} > 0.25 \times m_{eff}$

$m_{eff} > 500$ GeV

$$m_{eff} = E_T^{miss} + p_T^{lep} + \sum_0^3 p_T^{jet\ i}$$

1-lepton channel

$\int L\,dt \sim 35\ pb^{-1}$

Backgrounds

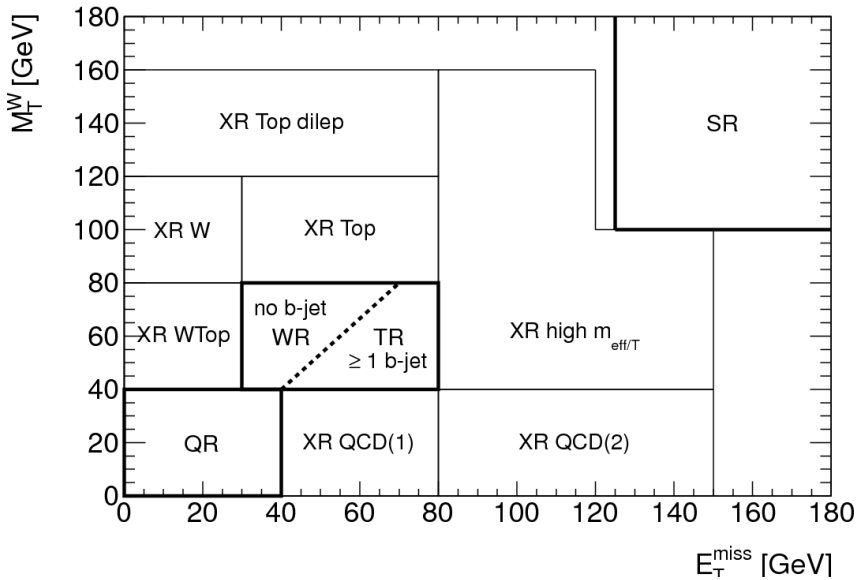
SR Signal region

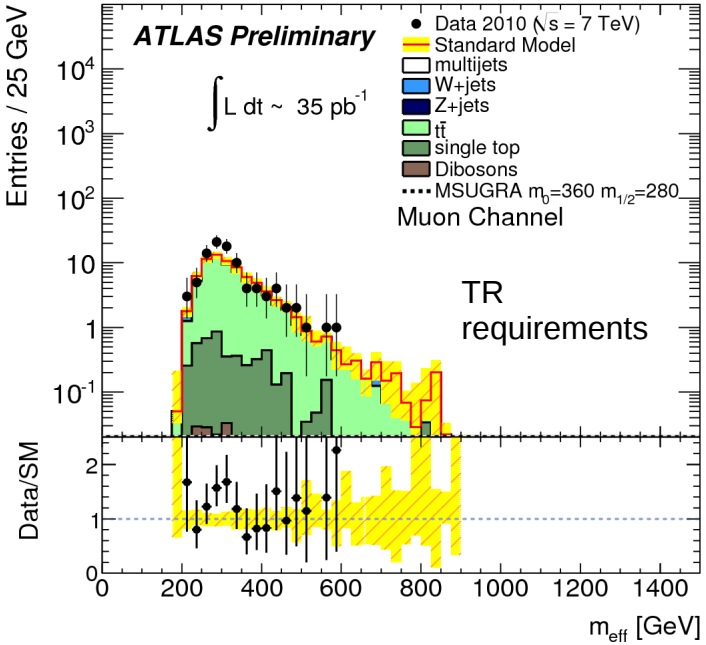
TR Top-rich region

WR W-rich region

QR QCD multijets-rich region

XR cross-check regions





Top quark pairs, W+jets
Estimated from a combined fit to observed events in control regions
+ MC to estimate signal contamination in control regions

QCD multijets background (jet misidentified as lepton)
Estimation purely data driven (loose-tight method)
QR used to estimate QCD multijets contribution to other control regions

Other backgrounds MC estimation

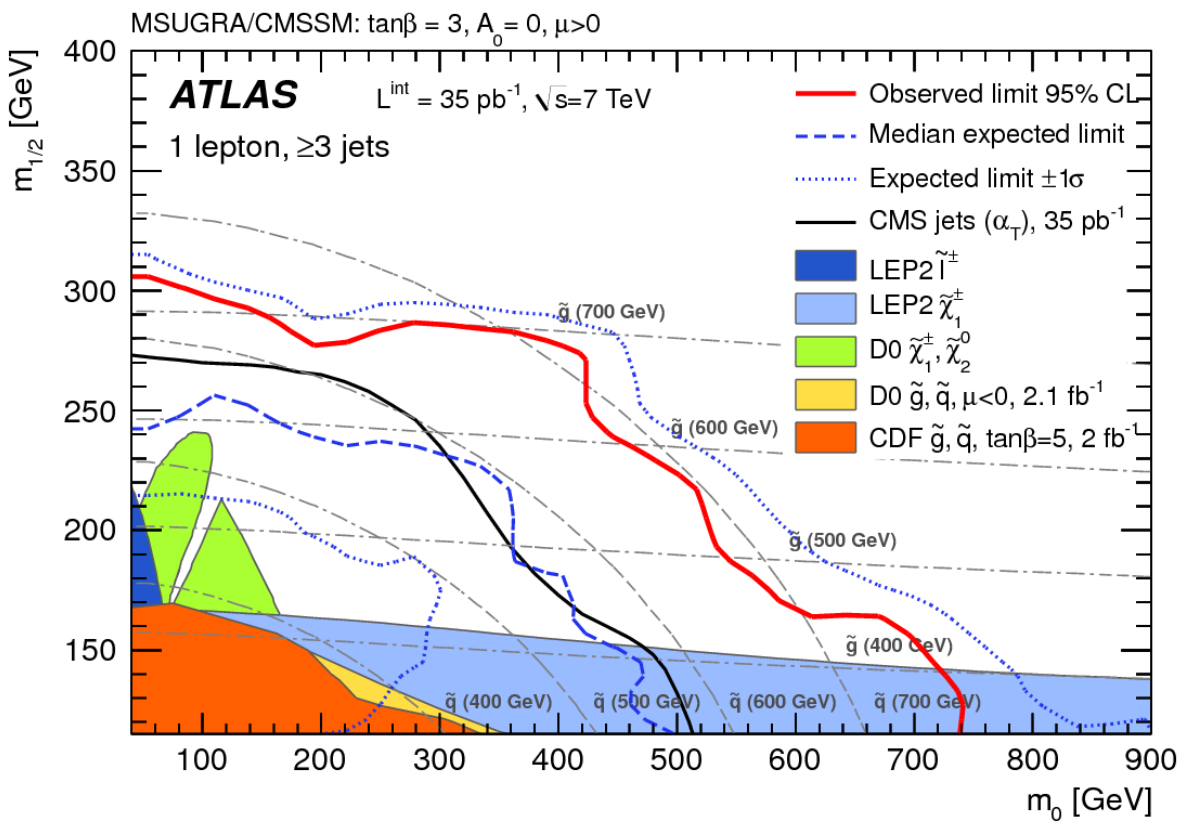
B-tagging
SV0 = *L/σ(L)* used - lifetime-based tagging algorithm relying on the explicit reconstruction of secondary vertices within jets
For p_T > 60 GeV, ε_b = 50 %, mistag rate of 0.5% for light-quark jets
where L is the distance of the secondary vertex to the primary vertex

1-lepton results

$\int L\,dt \sim 35\ pb^{-1}$

1 event observed in the electron channel: Σbackground 1.81±0.75
1 event observed in the muon channel: Σbackground 2.25±0.94

mSUGRA/CMSSM
Profile likelihood used to set a 95% CL upper limit on the effective σ
e-channel 0.065 pb, μ-channel 0.073 pb



$$m(\tilde{g}) \sim m(\tilde{q}) < 700\ \text{GeV}$$
excluded at 95% CL

Observed limit vs expected limit
Observed is better than expected limit because $N_{obs} < N_{exp}$

The expected limit bands
Any observation of number of events in the signal region that agrees with the background-only prediction within 68% CL, gives an observed exclusion limit that lies within the 1-sigma uncertainty band.

0-lepton + 1-lepton channel combination

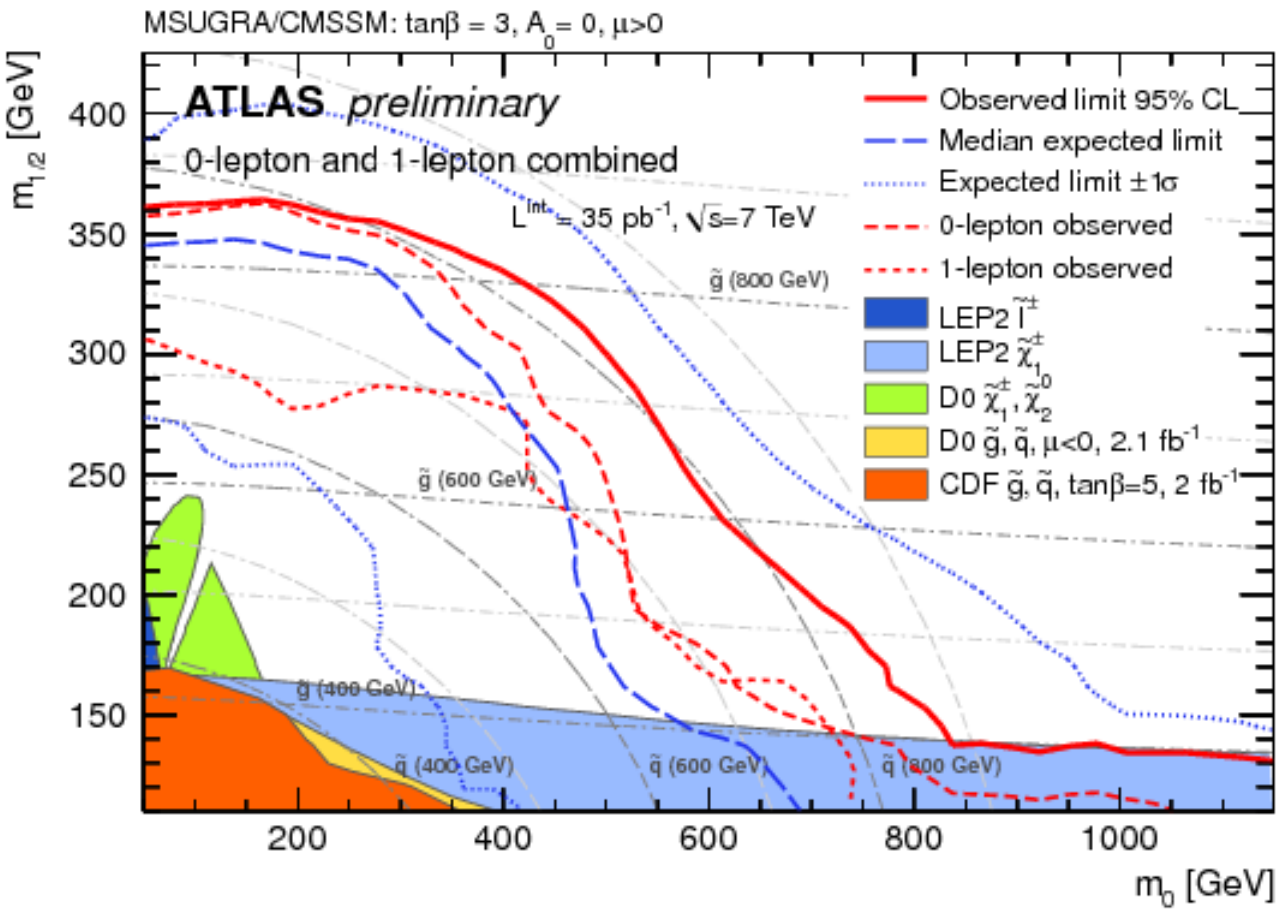
$\int L\,dt \sim 35\ pb^{-1}$

ATLAS-CONF-2011-064

0-lepton and 1-lepton channel are statistically exclusive

Profile likelihood ratio method used to set a 95% CL upper limit on the effective σ

$$m(\tilde{g}) = m(\tilde{q}) < 815 \text{ GeV excluded at 95\% CL}$$



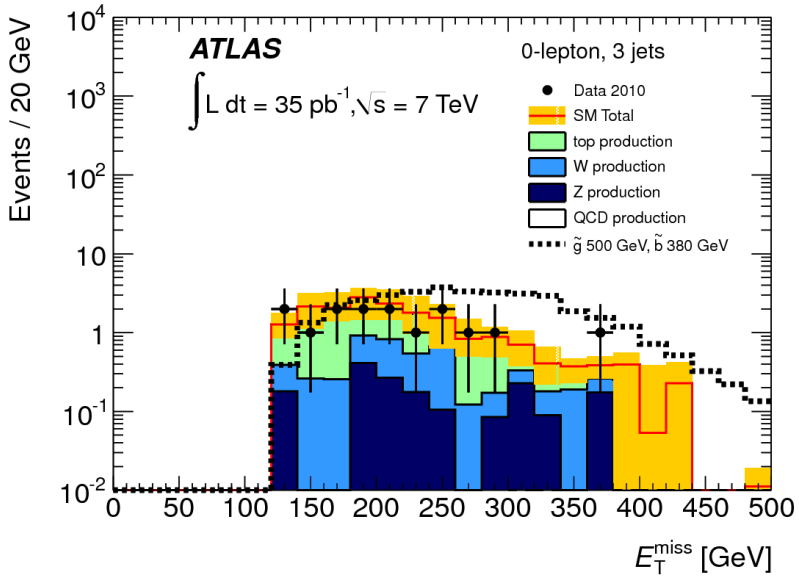
Total likelihood is the product of contributions from each channel, performed for each point on the SUSY scan grids

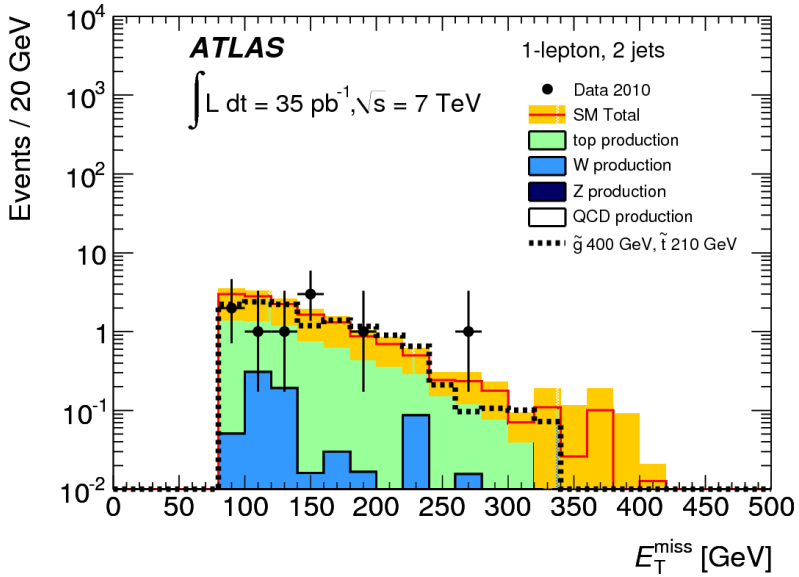
b-jet channels

$\int L\,dt \sim 35\ pb^{-1}$

arXiv:1103.4344

$\tilde{g} \to \tilde{b}_1 b$ $\qquad$ $\tilde{g} \to \tilde{t}_1 t \to \tilde{\chi}_1^{\pm} b t$





Signal Selection

0-lepton

high p_T jet + E_T^{miss} trigger
At least 3 jets $p_T > 120,\ 30,\ 30$ GeV
At least 1 b-tagged jet
$E_T^{miss} > 100$ GeV
$E_T^{miss} > 0.2 \times m_{eff}$
$\Delta\phi(\text{jet}_i, E_T^{miss}) > 0.4\ (i = 1,2,3)$
$m_{eff} > 600$ GeV

1-lepton

single lepton trigger
At least one electron or muon
At least 2 jets $p_T > 60,\ 30$ GeV
At least 1 b-tagged jet
$E_T^{miss} > 80$ GeV
$m_T > 100$ GeV
$m_{eff} > 500$ GeV

B-tagging
SV0 = *L/σ(L)* used - lifetime-based tagging algorithm relying on the explicit reconstruction of secondary vertices within jets
For $p_T > 30$ GeV, $\varepsilon_b = 50$ %, mistag rate of 1% for light-quark jets

b-jet channels

$\int L\,dt \sim 35\ pb^{-1}$

Backgrounds

Mainly top quark pairs (jets, E_t^{miss}, b-jets)

0-lepton

QCD multijets: MC normalised to QCD multijets-enriched control region $\Delta\varphi_{min}<0.4$ then MC counted in signal region.

Other backgrounds: MC prediction

Cut	$t\bar{t}$	$W+$ jets	Wbb	$Z+$ jets	Zbb	single top
$E_T^{miss} > 100$ GeV	3.55 ± 0.02	9.29 ± 0.15	0.1 ± 0.01	4.66 ± 0.14	0.054 ± 0.002	0.30 ± 0.02
$E_T^{miss}/m_{eff} > 0.2$	3.05 ± 0.02	8.36 ± 0.14	0.09 ± 0.01	4.28 ± 0.14	0.047 ± 0.001	0.26 ± 0.02
1 b-tagged jet	2.15 ± 0.02	0.69 ± 0.04	0.06 ± 0.01	0.28 ± 0.03	0.022 ± 0.001	0.16 ± 0.01
$\Delta\phi_{min} > 0.4$	1.60 ± 0.02	0.42 ± 0.03	0.05 ± 0.01	0.19 ± 0.03	0.016 ± 0.001	0.11 ± 0.01
$m_{eff} > 600$ GeV	0.33 ± 0.01	0.11 ± 0.02	0.006 ± 0.002	0.05 ± 0.01	0.0031 ± 0.0003	0.02 ± 0.01

1-lepton

Fake/non-isolated lepton from QCD multijets. Purely data driven.

Others: control regions using m_T and m_{eff}.

Region	Data	Monte Carlo
A: $40 < m_T < 100$ GeV and $m_{eff} < 500$ GeV	103	105.1 ± 1.5
B: $m_T > 100$ GeV and $m_{eff} < 500$ GeV	46	35.9 ± 0.5
C: $40 < m_T < 100$ GeV and $m_{eff} > 500$ GeV	33	40.1 ± 0.8
D: $m_T > 100$ GeV and $m_{eff} > 500$ GeV	9	13.5 ± 0.4
Estimation	14.7 ± 3.7	13.7 ± 0.4
Ratio	(164 ± 41) %	(101.2 ± 2.9)%

Results

0-lepton channel 15 events observed: Σbackground 19.6±6.9

1-lepton channel 9 events observed: Σbackground 13.5±4.1 from MC
(14.7±3.7 data-driven)

b-jet results

$\int L\,dt \sim 35\ pb^{-1}$

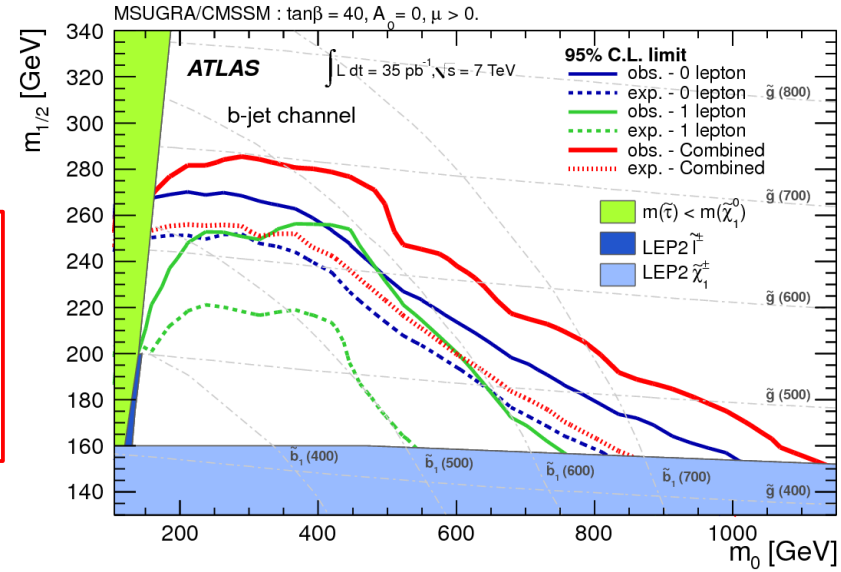
mSUGRA/CMSSM framework.

Profile likelihood used to set a 95% CL upper limit on the effective σ
0-lepton channel 0.32 pb, 1-lepton channel 0.13 pb

$m(\tilde{b}) < 550$ and $m(\tilde{t}) < 470$ GeV excluded at 95% CL

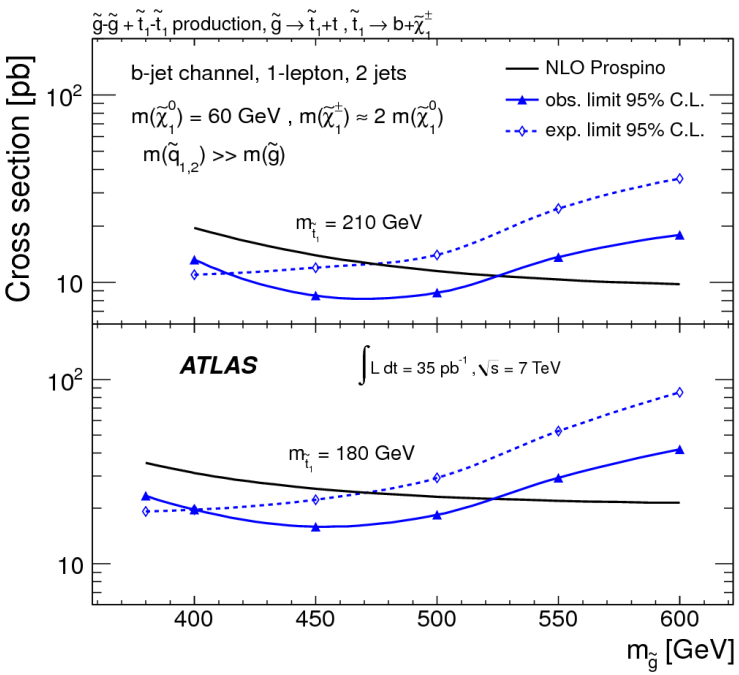
$m(\tilde{g}) \sim m(\tilde{q}) < 600$ GeV excluded at 95% CL

$m(\tilde{g}) < 500$ GeV excluded at 95% CL for 100 GeV $< m_0 <$ 1 TeV



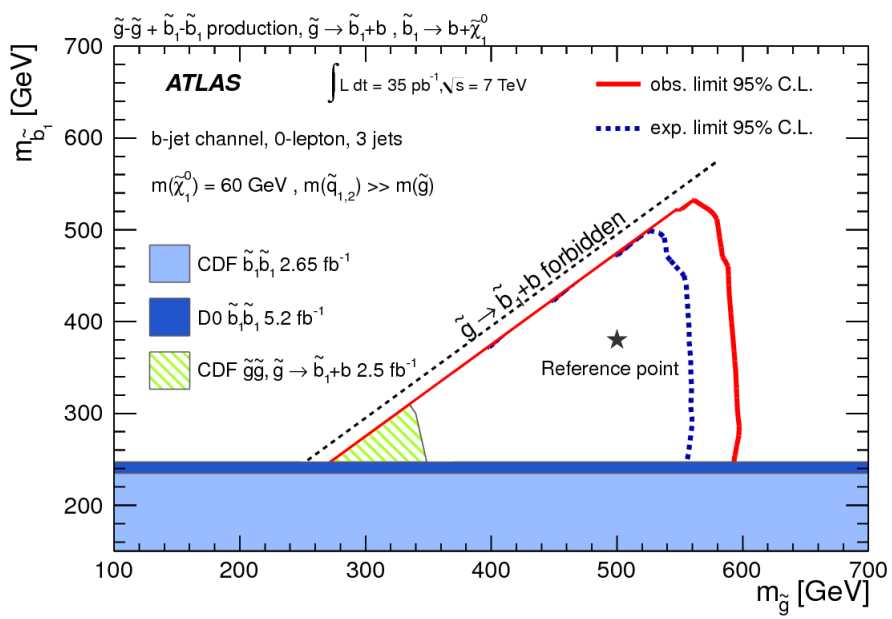
1-lepton
Lightest $\tilde{t}_1$ produced via gluino-mediated or direct pair production and decays via $\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^{\pm}$

$m(\tilde{g}) < 520$ GeV excluded at 95% CL for 130 GeV $< m(\tilde{t}) <$ 300 GeV



0-lepton
Lightest squark $\tilde{b}_1$ produced via gluino-mediated or direct pair production and decays via $\tilde{b}_1 \rightarrow b\,\tilde{\chi}_1^{0}$

$m(\tilde{g}) < 590$ GeV excluded at 95% CL for $m(\tilde{b}) < 500$ GeV

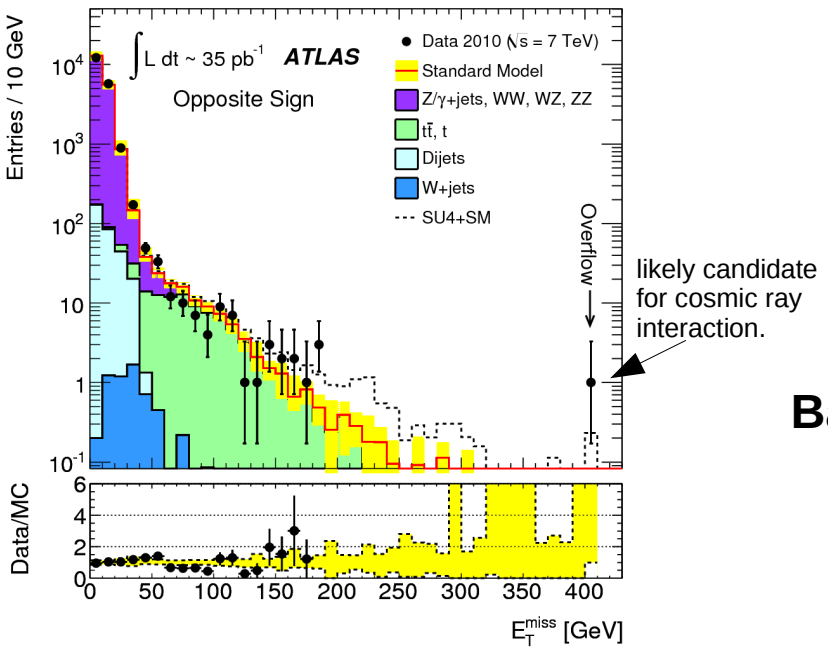


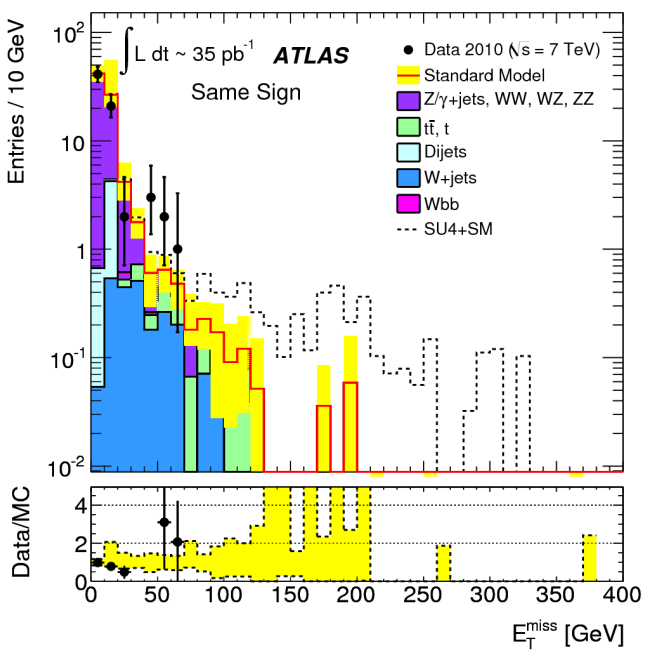
2-lepton channel

$\int L\,dt \sim 35\ pb^{-1}$

arXiv:1103.6214 Submitted to EPJC letters

$$\tilde{\chi}_i^{\pm} \rightarrow l^{\pm} \nu \tilde{\chi}_j^0 \qquad \tilde{\chi}_i^0 \rightarrow l^+ l^- \tilde{\chi}_j^0$$





Signal Selection

Exactly 2 leptons $p_T > 20,20$ GeV

Opposite Sign

$E_T^{miss} > 150$ GeV

Same Sign

$E_T^{miss} > 100$ GeV

Backgrounds

Opposite Sign

Top quark pairs, Z+jet, di-boson and single-top

Top-tagged control region using $60 < E_T^{miss} < 80$ GeV and m_{CT}

Z control region using low-E_T^{miss} and Z-mass peak

Same Sign

Mainly SM + fake/non-isolated lepton: top quark pairs, single-top, W+jets, QCD multijets. Purely data driven.

$Z \rightarrow e^{\pm}e^{\pm}$ estimated from MC+data

Results

Opposite Sign

9 events observed: Σbackground 3.7±1.6

Probability for background to exceed observed events 12.8%

Same Sign

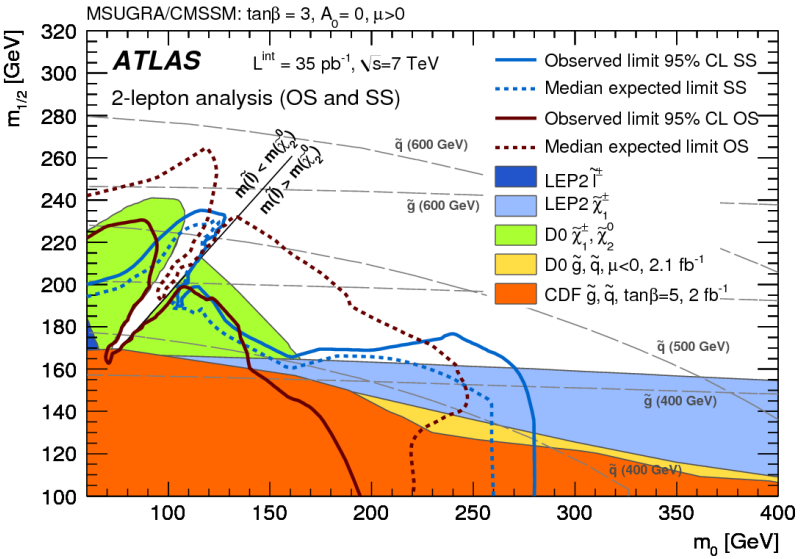
0 events observed: Σbackground 0.28±0.14

2-lepton results

$\int L\,dt \sim 35\ pb^{-1}$

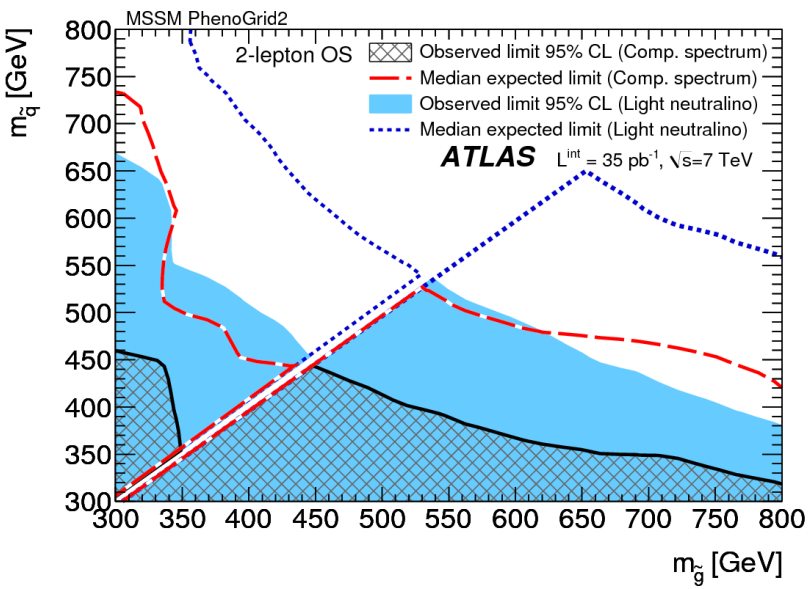
Limits are set on new physics in the mSUGRA/CMSSM framework

Profile likelihood used to set a 95% CL upper limit on the effective σ
Opposite Sign channel: 0.09 pb (e^+e^-),
0.21 pb ($\mu^+\mu^-$),
0.22 pb ($e^+\mu^-, e^-\mu^+$)
Same Sign channel 0.07 pb

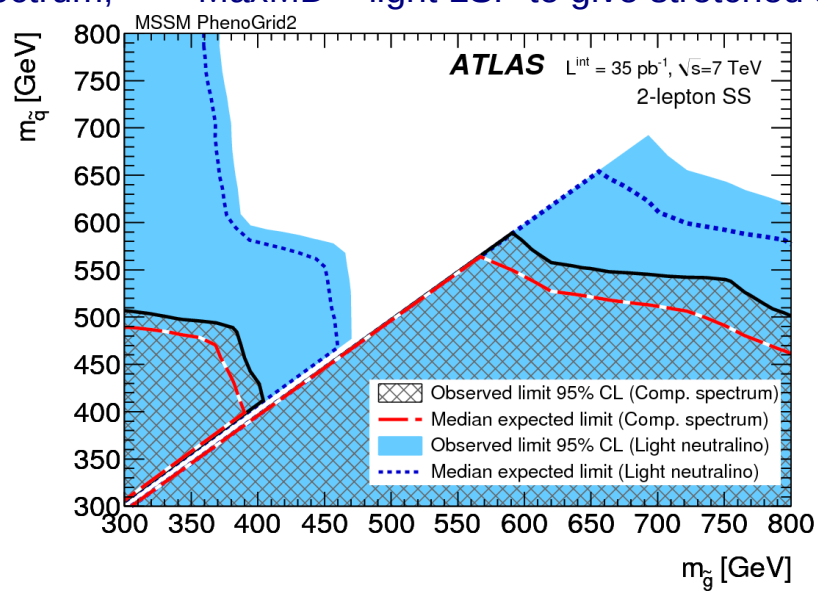


Phenomenological grids

Like mSUGRA phenomenology (bino-like $\tilde{\chi}_1^0$, wino-like $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$) but no enforced mass relations.
Masses of $\tilde{g}$, $\tilde{q}$, $\chi_2^0 = \chi_1^{\pm}$, $\tilde{l}$, χ_1^0 are varied freely.
3rd gen. scalars out of reach. Leptonic decays boosted by choosing slepton mass between wino and bino sectors.
2 modes: MinMD – LSP mass lifted to give compressed spectrum, MaxMD – light LSP to give stretched spectrum.



MinMD (MaxMD) $m(\tilde{q}) < 450\ (550)$ GeV excluded at 95% CL



MinMD (MaxMD) $m(\tilde{q}) < 590\ (690)$ GeV excluded at 95% CL

e-μ resonance

∫ L dt ~ 35 pb^{-1}

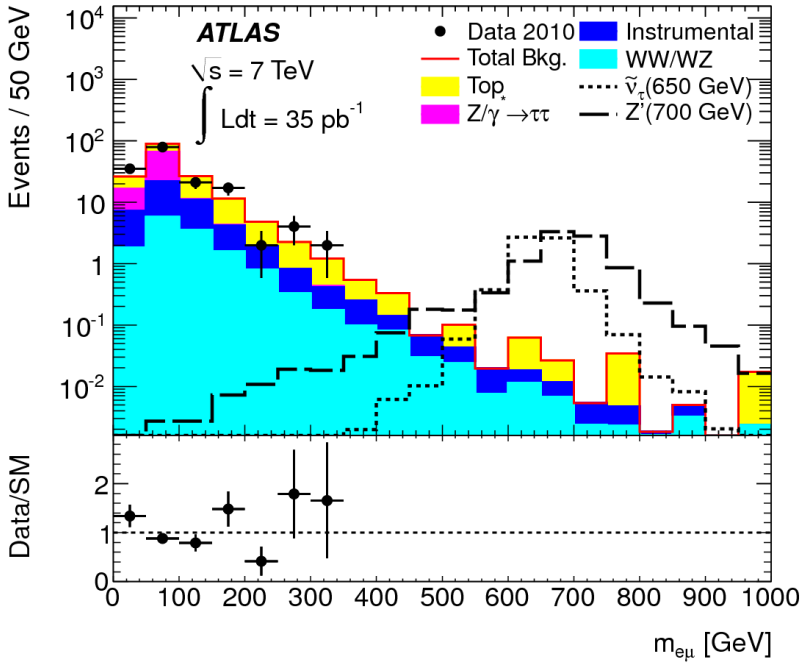
arXiv:1103.5559 Submitted to PRL

R-Parity Violation

$\tilde{\nu} \rightarrow e^{\pm}\mu^{\mp}$

Extra Gauge Bosons + Lepton Flavour Violation (low σ)

$Z' \rightarrow e^{\pm}\mu^{\mp}$



Process	Number of events
$Z/\gamma^* \rightarrow \tau\tau$	54±7
$t\bar{t}$	57±9
WW	13.4±1.7
Single top	4.6±0.9
WZ	0.79±0.11
Instrumental background	33^{+30}_{-10}
Total background	163^{+34}_{-18}
Data	160

Signal Selection

1 isolated electron $p_T > 20$ GeV,
1 isolated muon $p_T > 20$ GeV,
Opposite charge leptons

Backgrounds

80% top, Z/γ* → ττ, WW, WZ and ZZ
MC estimated
Z → ll studied to correct MC (ε, scale, resolution)

20% "instrumental" background
Estimated from data (loose-tight method)
- misidentified jets, (heavy flavour) hadron decays, γ conversions
- W(→μν)γ and Z(→μμ)γ (MC estimation)

Results

160 events observed: Σbackground $163\pm^{34}_{18}$

No evidence for any peak structure in $m_{e\mu}$ distribution

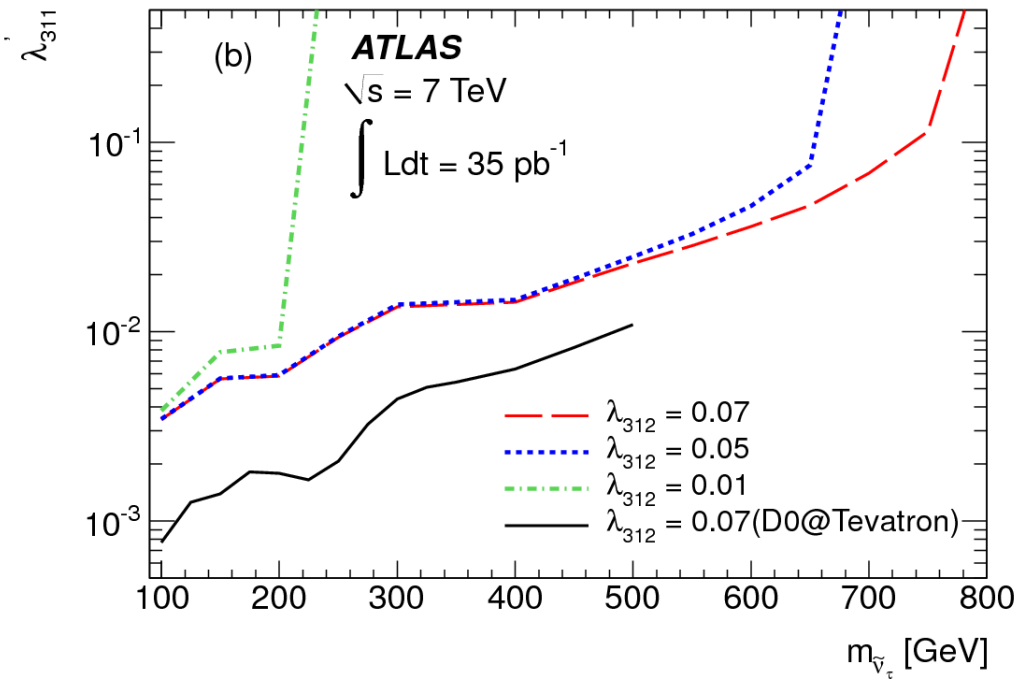
e-μ resonance results

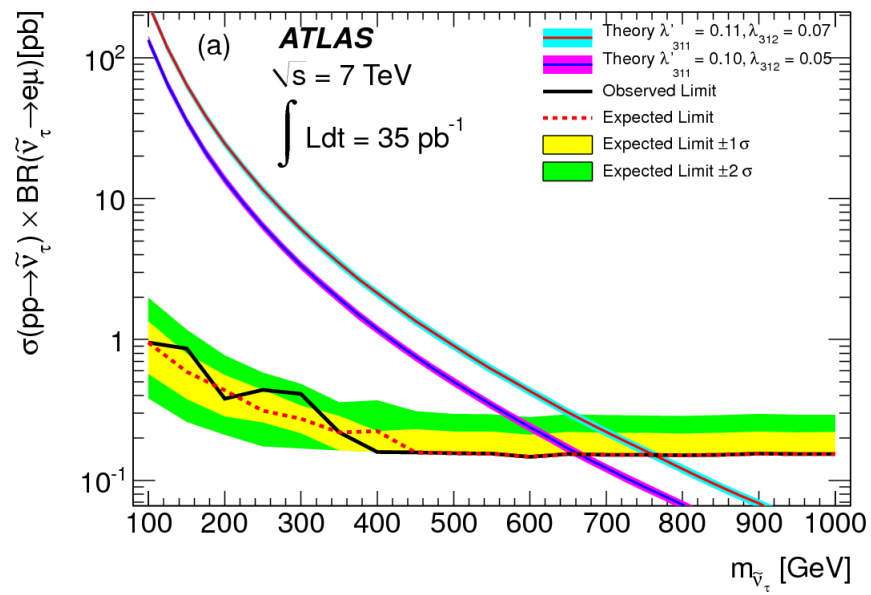
$\int L\,dt \sim 35\ pb^{-1}$

Limits are set on $\tilde{\nu}_\tau$ production in RPV SUSY models

for $m(\tilde{\nu}) = 100$ GeV, $\sigma \times BR < 0.951$ pb
for $m(\tilde{\nu}) = 1$ TeV, $\sigma \times BR < 0.154$ pb

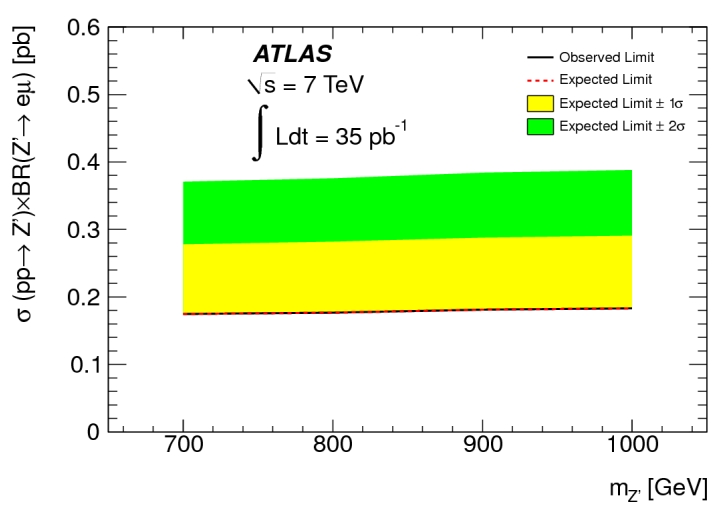
$m(\tilde{\nu}) < 750$ GeV for $(\lambda'_{311} = 0.11,\ \lambda'_{312} = 0.07)$
$m(\tilde{\nu}) < 650$ GeV for $(\lambda'_{311} = 0.10,\ \lambda'_{312} = 0.05)$
excluded at 95% CL





Limits are set on lepton flavour violating Z' using events with $m_{e\mu} > 400$ GeV

for $m(Z') = 700$ GeV, $\sigma \times BR < 0.175$ pb
for $m(Z') = 1$ TeV, $\sigma \times BR < 0.183$ pb

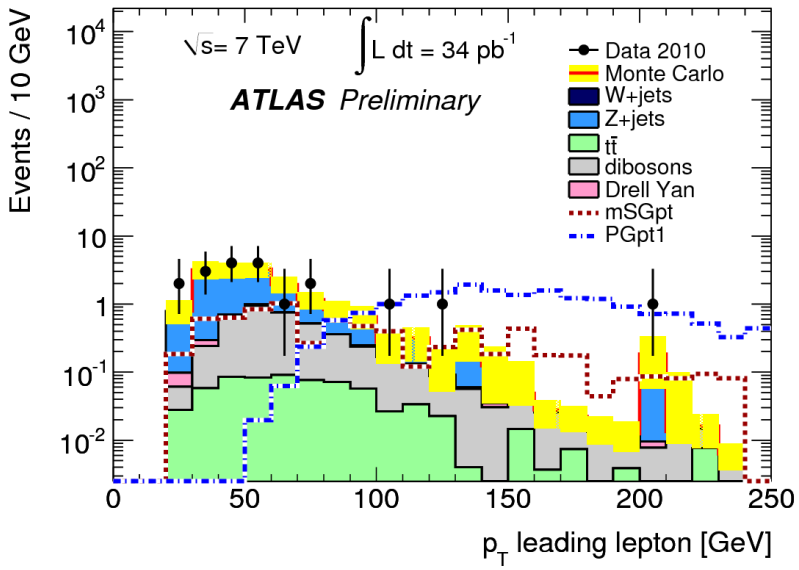


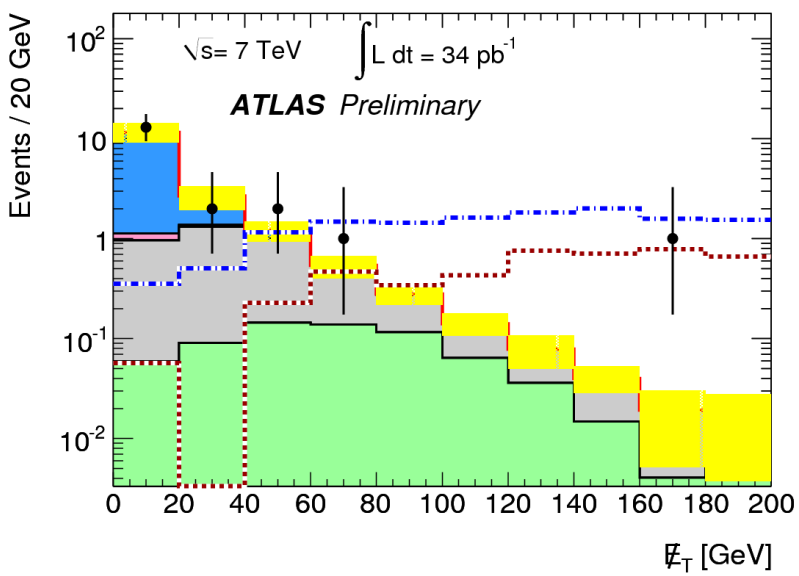
3-lepton channel

$\int L\,dt \sim 34\ pb^{-1}$

ATLAS-CONF-2011-039

$\tilde{\chi}_i^{\pm} \to l^{\pm} \nu \tilde{\chi}_j^0$ $\tilde{\chi}_i^0 \to l^+ l^- \tilde{\chi}_j^0$





Signal Selection

At least 3 leptons $p_T > 20,20,20(10)$ GeV $e(\mu)$

No SFOS pair with $|M_{SFOS} - M_Z| < 10$ GeV

At least 2 jets $p_T > 50,\ 50$ GeV

$E_T^{miss} > 50$ GeV

Backgrounds

Very low backgrounds

Top quark pairs main background

MC estimation for all backgrounds

Results

0 events observed: Σbackground $0.109 \pm 0.023^{+0.036}_{-0.025}$

At three-lepton stage:

Multilep. events	All	eee	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
$t\bar{t}$	0.68±0.16	0.032±0.016	0.24±0.07	0.31±0.08	0.096±0.030
Z backgrounds	15.6±1.3	3.8±0.8	1.60±0.34	7.9±1.0	2.4±0.4
Other backgrounds	0.28±0.13	0.02±0.14	0.03±0.06	0.21±0.09	0.01±0.11
Total SM	16.6±1.3	3.8±0.8	1.9±0.4	8.4±1.0	2.5±0.4
Data	19	2	1	10	6

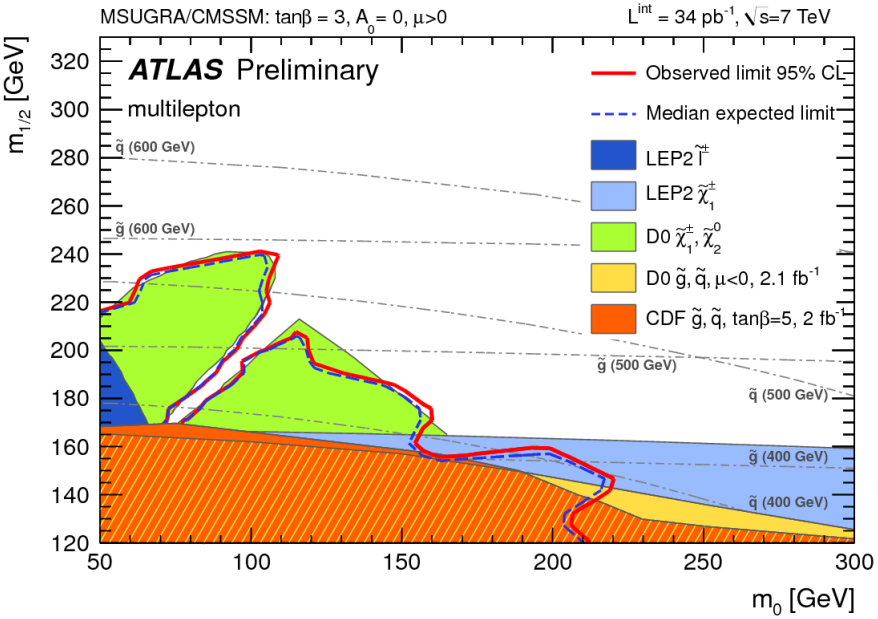
No events with 4 or more leptons are observed

3-lepton results

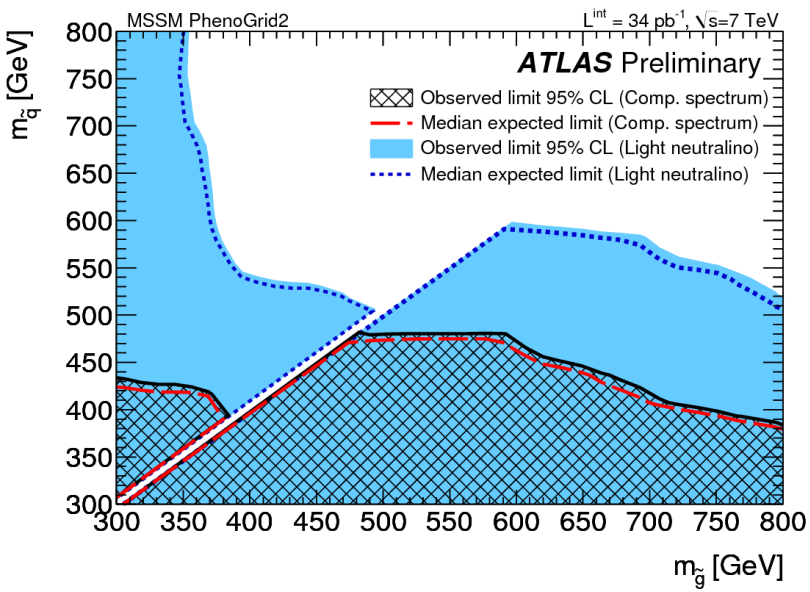
$\int L\,dt \sim 34\ pb^{-1}$

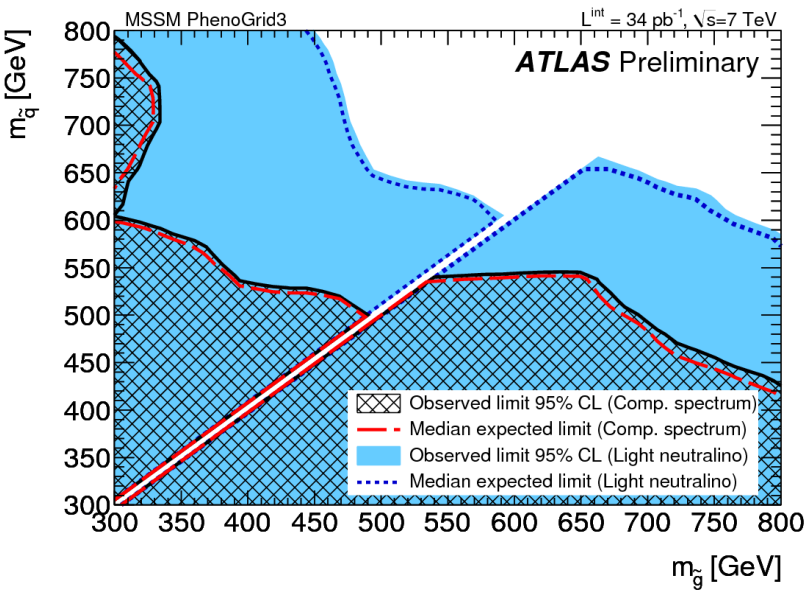
mSUGRA/CMSSM framework
Similar to Tevatron limits

Profile likelihood used to set a 95% CL upper limit on the effective σ of 0.062 pb



Phenomenological grids
As decribed on slide 7
Plus PhenoGrid3 has heavy right-handed squarks and sleptons → decreased σ, but increased leptonic BR.





MinMD (MaxMD) $m(\tilde{q}) < 480\ (600)$ GeV excluded at 95% CL

MinMD (MaxMD) $m(\tilde{q}) < 540\ (670)$ GeV excluded at 95% CL

Stable squarks and gluinos

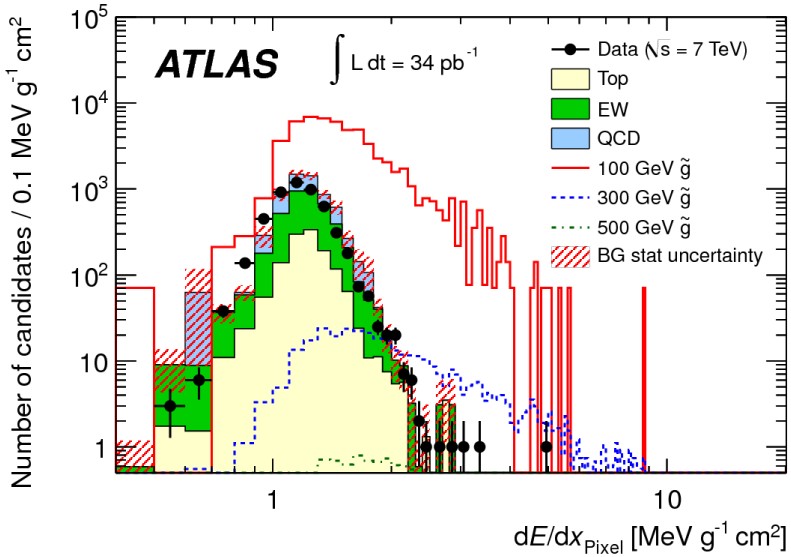
$\int L\,dt \sim 34\ pb^{-1}$

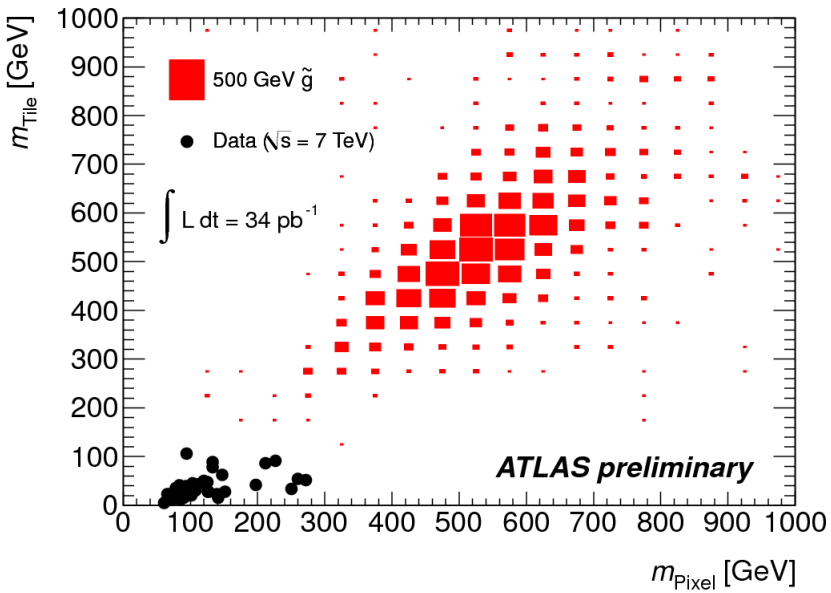
arXiv:1103.1984 accepted by PLB

R-hadrons: heavy objects formed from a coloured sparticle + light SM parton

Many models predict massive stable hadrons
– slow moving and penetrating

Exploit ATLAS time-of-flight and ionisation loss measurements
Measure dE/dx in the pixel detector
Measure time-of-flight in the tile calorimeter (resolution ~1 ns)





Signal Selection

high E_T^{miss} trigger

High-quality track $p_T > 50$ GeV, $|\eta| < 1.7$

Isolated from jets with $p_T > 40$ GeV

using $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 0.5$

$$M = \frac{p}{\beta\gamma} > 100\ \text{GeV}$$

$$\frac{dE}{dx_{Pixel}} > 1.8\ \text{MeV}\,\text{g}^{-1}\,\text{cm}^2$$

Backgrounds

Data driven estimation of background from instrumental effects

Exploit lack of correlation between p and β
Predict tails of dE/dx_{Pixel} and β_{Tile} distributions

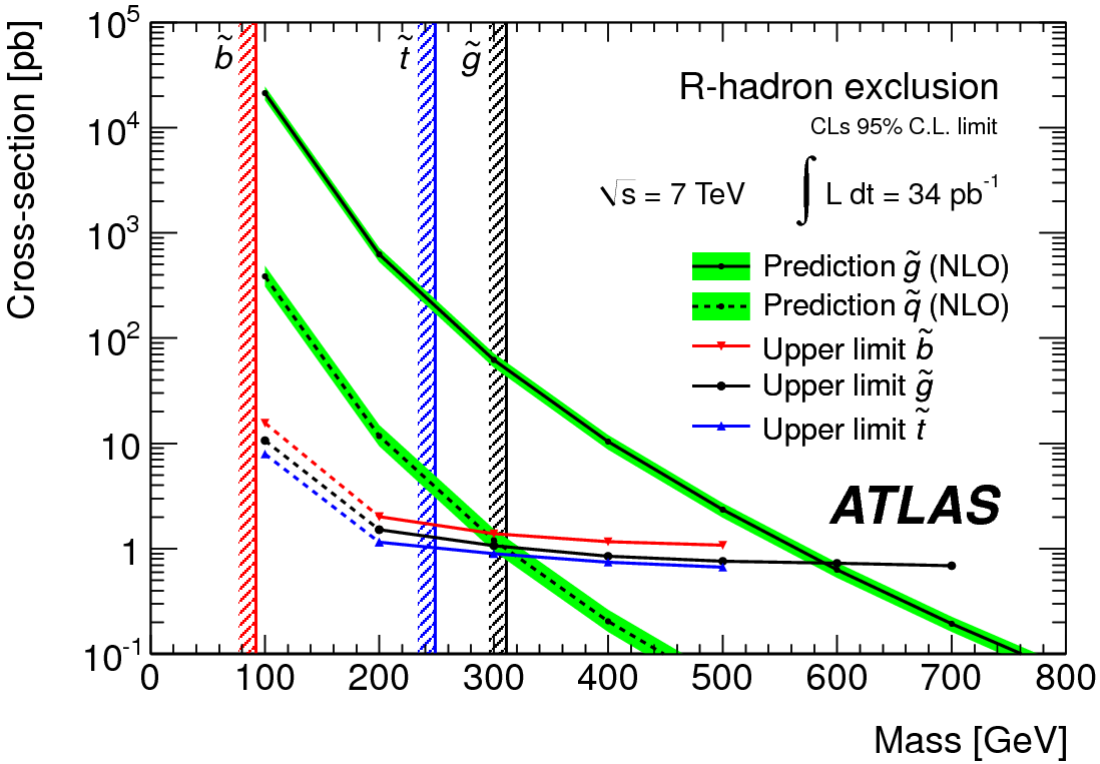
Sample dE/dx_{Pixel} and β_{Tile} to estimate background mass distributions

Stable squarks and gluinos results

$\int L\,dt \sim 34\ pb^{-1}$

Mass > (GeV)	Background	Data
100	5.4	5
200	0.87	0
300	0.33	0
400	0.082	0
500	0.044	0
600	0.028	0
700	0.018	0

CL_s used to set a 95% CL lower limit on the R-hadron mass in the context of SUSY

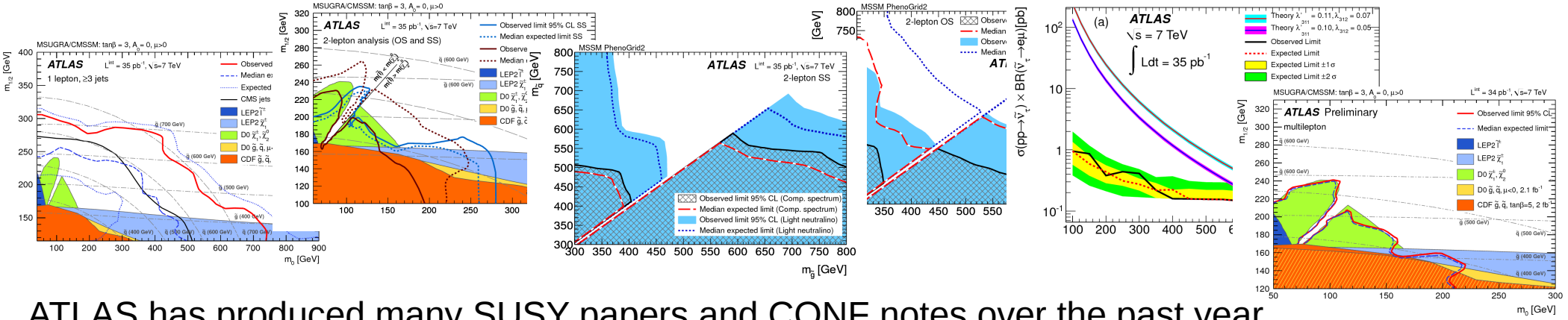


$m(\tilde{b}\ \text{R-hadron}) < 294\ \text{GeV excluded at 95\% CL}$

$m(\tilde{t}\ \text{R-hadron}) < 309\ \text{GeV excluded at 95\% CL}$

$m(\tilde{g}\ \text{R-hadron}) < 586\ \text{GeV excluded at 95\% CL}$

Summary



ATLAS has produced many SUSY papers and CONF notes over the past year

2010 data (35 pb^{-1}) is in agreement with the Standard Model

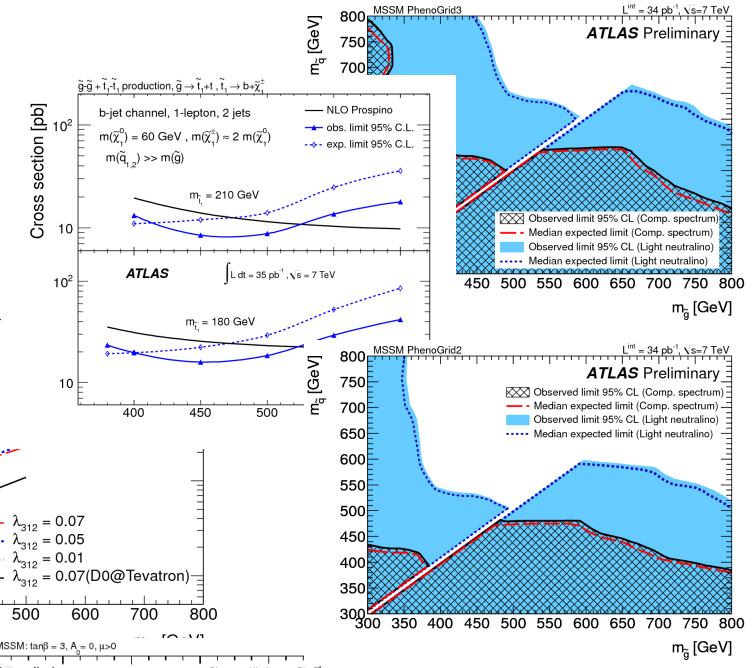
Limits set on SUSY particle masses and cross-sections

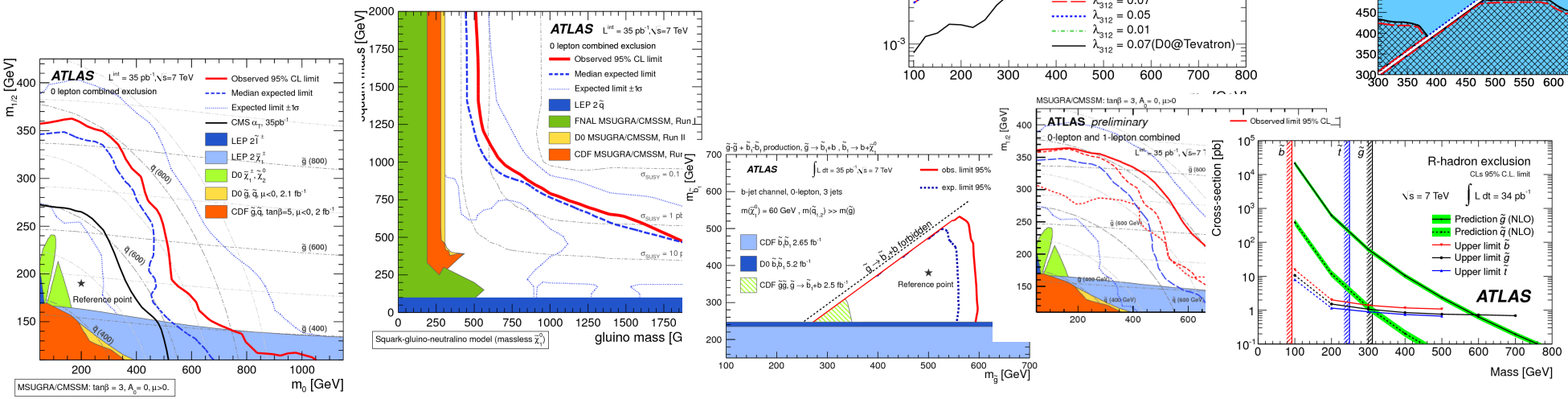
Pushing the excluded regions of SUSY parameter space

More papers expected this year.

Refining analyses for higher luminosity.

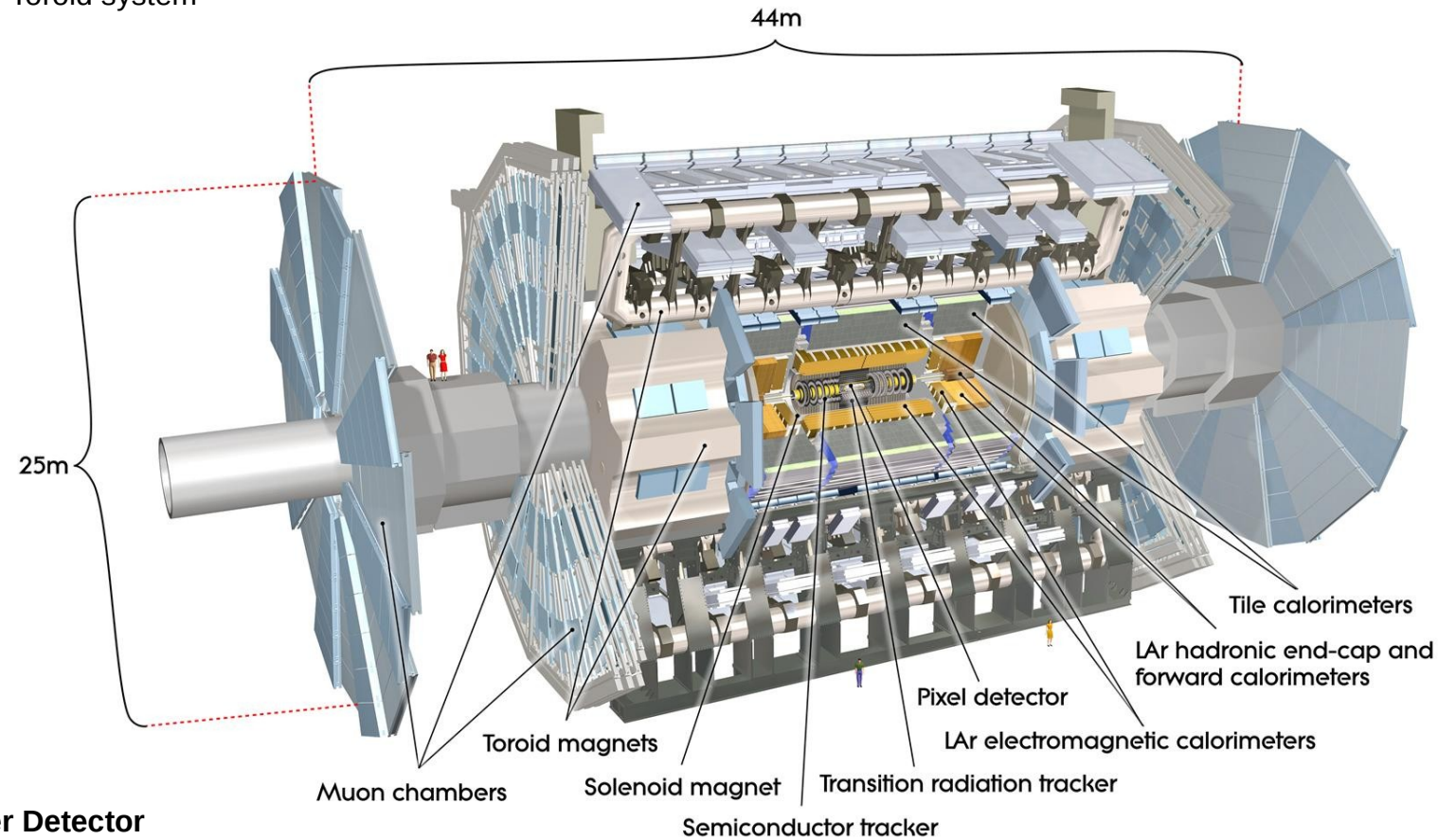
<u>2011 will be very exciting for new physics!!</u>





Backup – The ATLAS detector

Magnets
5 tonne central solenoid: 2T in inner detector
4T Toroid system



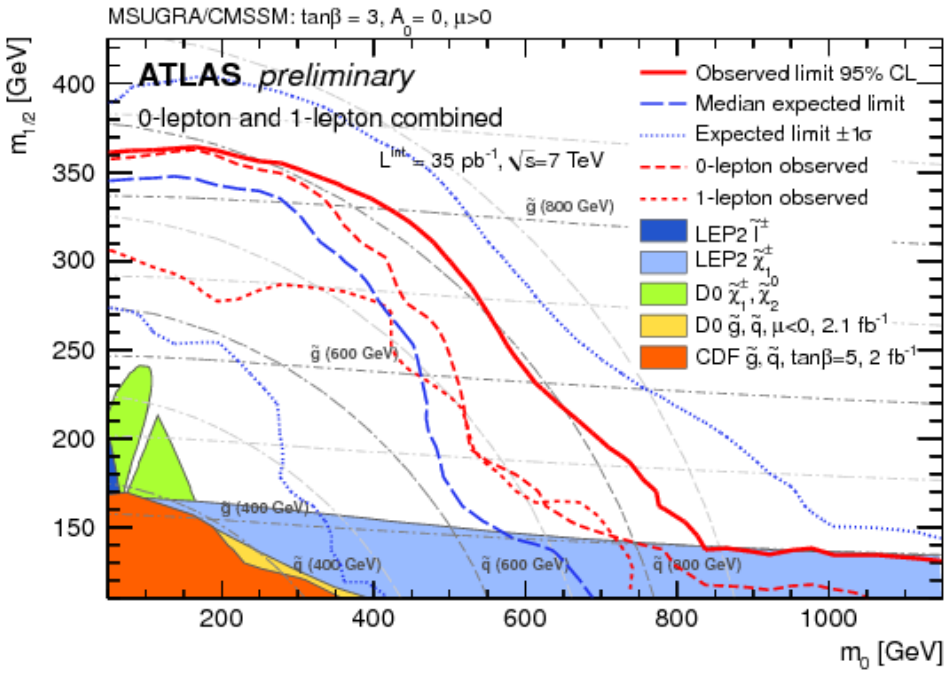
Inner Detector
|η|<2.5, B=2T
Precise tracking and vertexing
Silicon Pixels, Strips and TRT straws

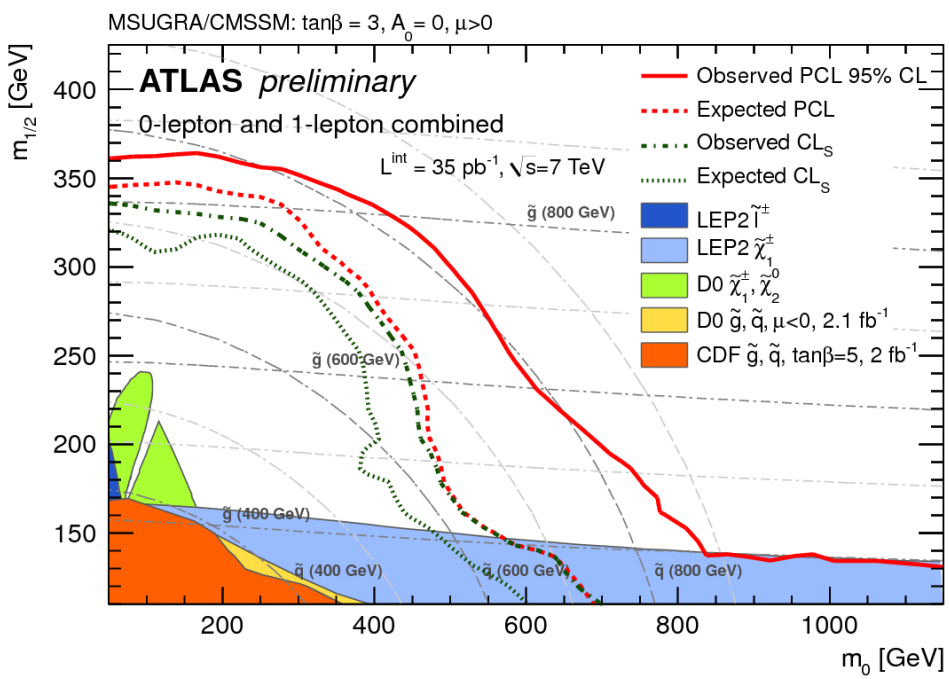
Muon Spectrometer
|η|<2.7
Gas-based chambers

Electromagnetic Calorimeter
|η|<3.2
Layers of lead and LAr

Hadronic Calorimeter
|η|<5
Central: iron/scintillator tiles
Forward: copper/tungsten-LAr

Backup – 0-lepton + 1-lepton combination





PCL vs CL_s

Different handling when excluding signal hypotheses in regions with small sensitivities.

PCL sets limits based on CL_{s+b}.
Observed limit is not allowed to fluctuate below the -1σ expected limit.
Protects against excluding the (signal) null hypothesis in cases of downward fluctuations of the background.
Equivalent to restricting the interval to cases in which the statistical power of the test of μ against the alternative μ=0 is at least 16 %. If the observed limit fluctuates below the 16% power, the quoted limit is the -1σ expected limit.
In the PCL approach squarks and gluinos of equal mass are excluded below 815 GeV at 95% C.L.

CL_s = CL_{s+b}/CL_b
Corrects for downward fluctuations continuously. Over-covers compared with PCL.
Case of downward fluctuations in data results in smaller observed exclusion limits, which are closer to the expected exclusion limits.
Observed and expected CL_s exclusion contours lie closer to each other.
Less restrictive than PCL over the entire m0, m1/2 plane.
In the CL_s approach squarks and gluinos of equal mass are excluded below 730 GeV at 95% C.L. (where CL_b = 0.33)

The power constraint never had to be applied, as the observed limit never fluctuated by more than 1σ below the expected limit,