Searches for strong R-parity conserving SUSY production at the LHC with the ATLAS detector

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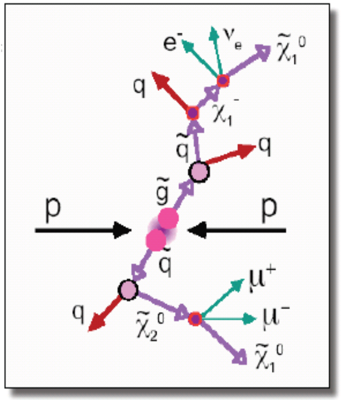
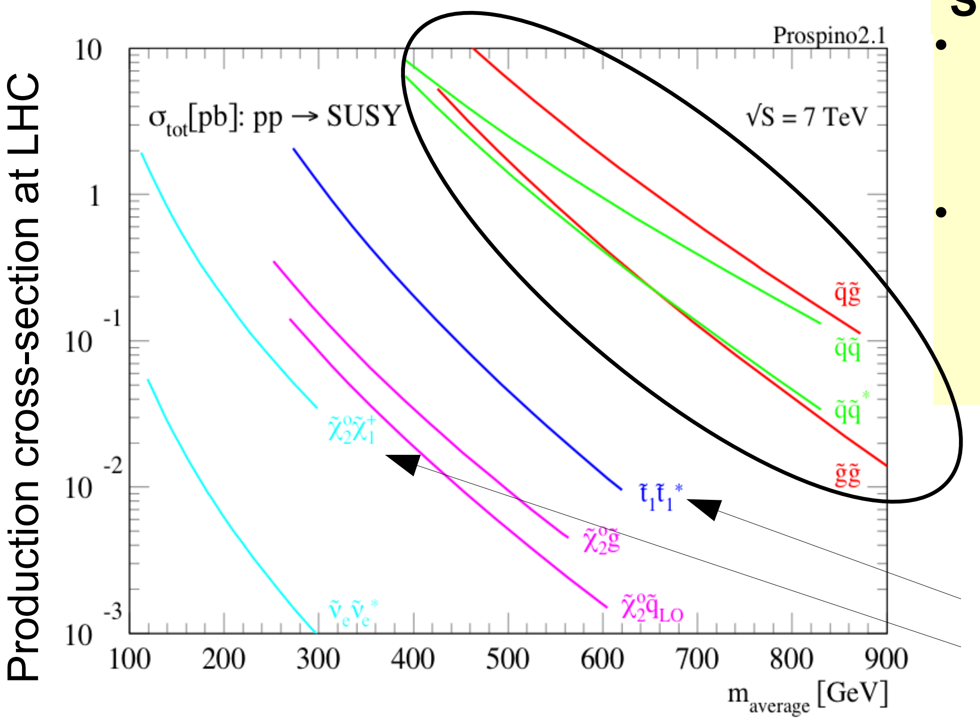
On behalf of the ATLAS Collaboration

SUSY searches in ATLAS

Focus on general R-parity conserving SUSY models:

- LSP is stable → large missing transverse energy (E_T^{miss})
- Sparticles produced in pairs → cascade decays: high pt leptons and/or jets
- Look for an excess of events with respect to Standard Model (SM) predictions
- Main SM backgrounds: QCD, W/Z+jets, tt





Strong production: This talk

- squark-squark production (heavy gluinos):
  - final states with 2 or more jets, not many leptons → 0-lepton analysis
- gluino-gluino production (heavy squarks):
  - long decay chains, many jets and (possibly) leptons. → 0-lepton+multijet and 1-lepton analyses.

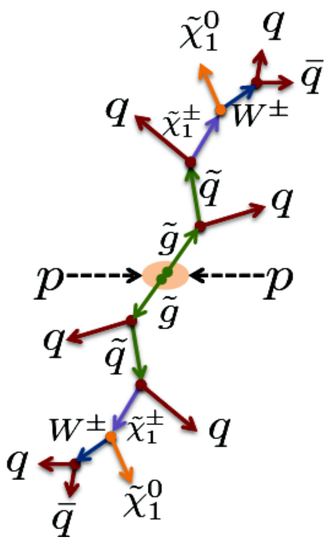
R-parity violating models: talk by Carsten Meyer

Direct stop/sbottom: talk by Carlos Alberto Chavez Barajas

Weak production: talk by Louise Helaan

} today!

0-lepton in a nutshell - 4.7 fb^{-1} ATLAS-CONF-2012-033



- Search for squark/gluino production in final states with jets, E_T^{miss} , and no leptons, sensitive to final states from squarks decaying directly (≥ 2 jets) to longer decay chains (≥ 6 jets);

- Signal/background discrimination based on the effective mass m_{eff} sensitive to the SUSY mass scale:

$$m_{\mathrm{eff}} = E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{\mathrm{SR\ jets}} p_{\mathrm{T}}$$

- 11 <u>inclusive</u> signal regions (SR), depending on jet multiplicities and m_{eff}:
  - From **2 to 6 jet multiplicities** and various combination of m_{eff} cuts:
  - Optimized to achieve maximal reach over ($m_{\tilde{q}}$,$m_{\tilde{g}}$) plane, and to enhance sensitivity to models with compressed spectra (small mass splitting)

- Backgrounds from multi-jet processes kept under control through cut on the minimum azimuthal angle ($\Delta\phi$) between the jets and E_T^{miss} ;

0-lepton in a nutshell - 4.7 fb^{-1} ATLAS-CONF-2012-033

- SM backgrounds from mismeasured multi-jet events, W/Z($\rightarrow \nu\nu$)+jets, tt in signal regions: estimated from background-enriched control regions (CR) through transfer factors (TF, data driven for QCD);

- For each signal region, 5 control regions:

CR	SR Background	CR process	CR selection
CR1a	$Z(\rightarrow \nu\nu)$+jets	γ+jets	Isolated photon
CR1b	$Z(\rightarrow \nu\nu)$+jets	$Z(\rightarrow \ell\ell)$+jets	$\|m(\ell,\ell) - m(Z)\| < 25$ GeV
CR2	QCD jets	QCD jets	Reversed $\Delta\phi(j_i, E_{\mathrm{T}}^{\mathrm{miss}})$ cut
CR3	$W(\rightarrow \ell\nu)$+jets	$W(\rightarrow \ell\nu)$+jets	30 GeV $< m_T(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV, b-veto
CR4	$t\bar{t}$ and single-t	$t\bar{t} \rightarrow bbqq'\ell\nu$	30 GeV $< m_T(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) <$ 100 GeV, b-tag

- A global fit for the normalisation of each background from the control regions is simultaneously performed separately for each signal region.

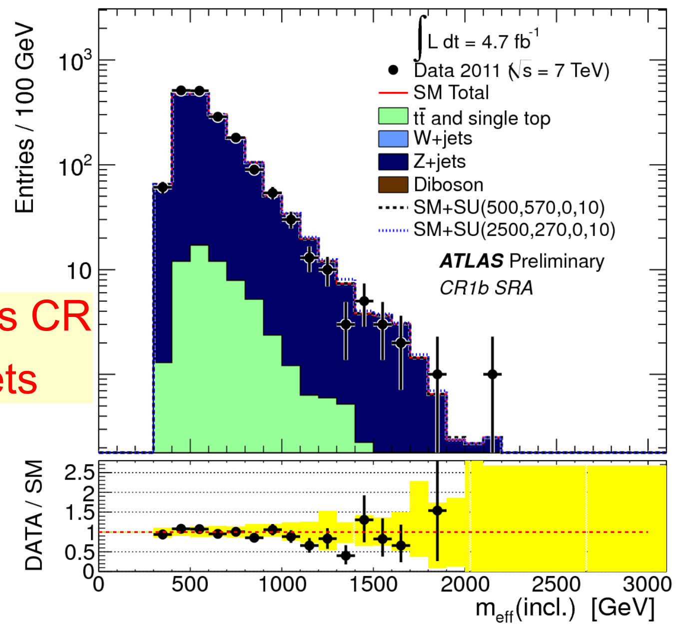
Update of previously published 1 fb^{-1} result: arXiv:1109.6572

0-lepton - Results

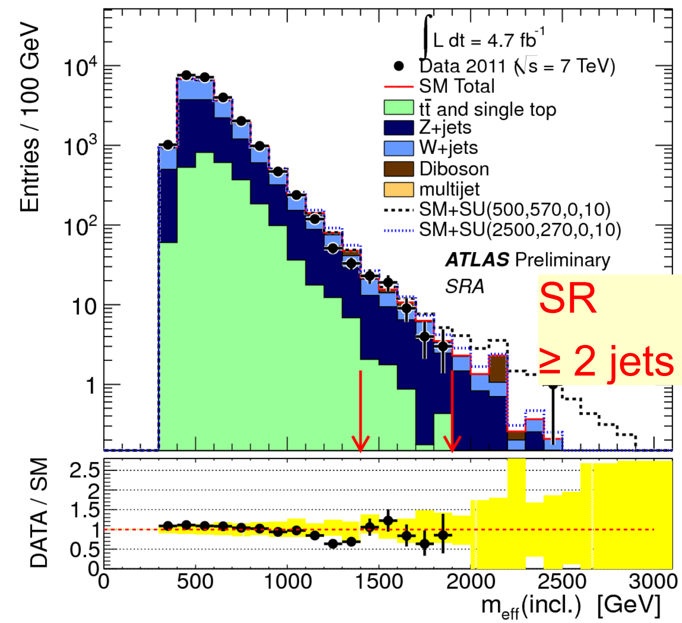
Control regions

$$N(\mathrm{CR}, \mathrm{obs}, \mathrm{proc}) \times \left[\frac{N(\mathrm{SR}, \mathrm{raw}, \mathrm{proc})}{N(\mathrm{CR}, \mathrm{raw}, \mathrm{proc})}\right] = N(\mathrm{SR}, \mathrm{est}, \mathrm{proc})$$

Z+jets CR
≥ 2 jets



Transfer function



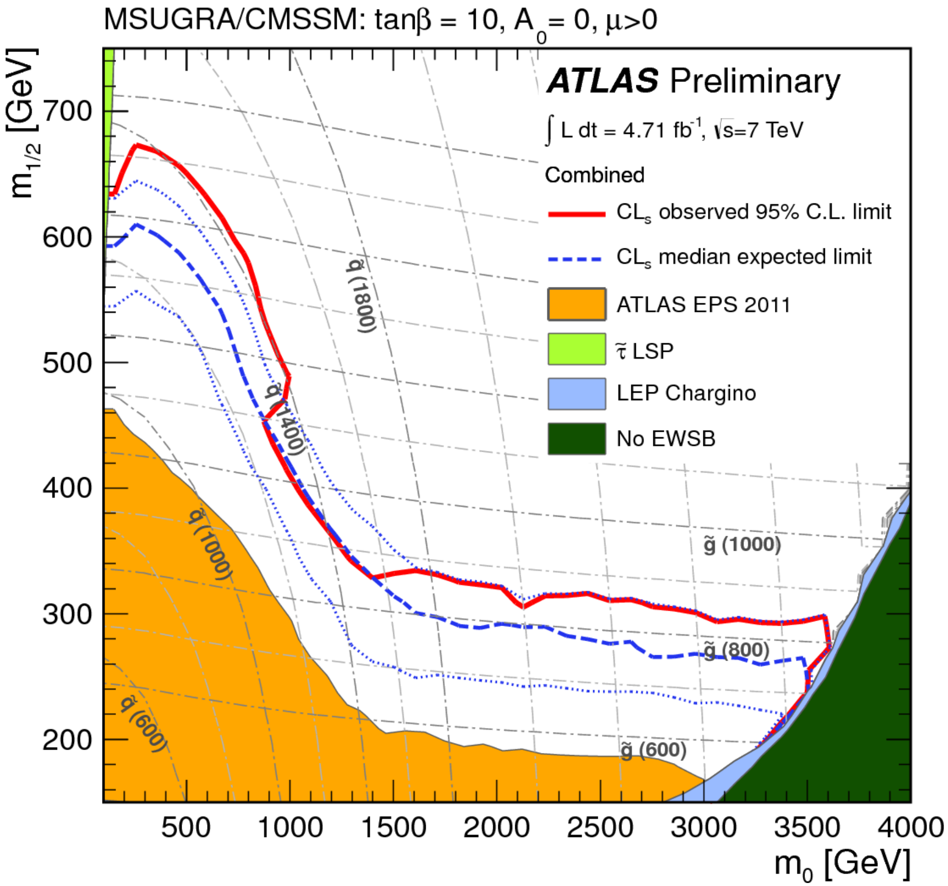
SR
≥ 2 jets

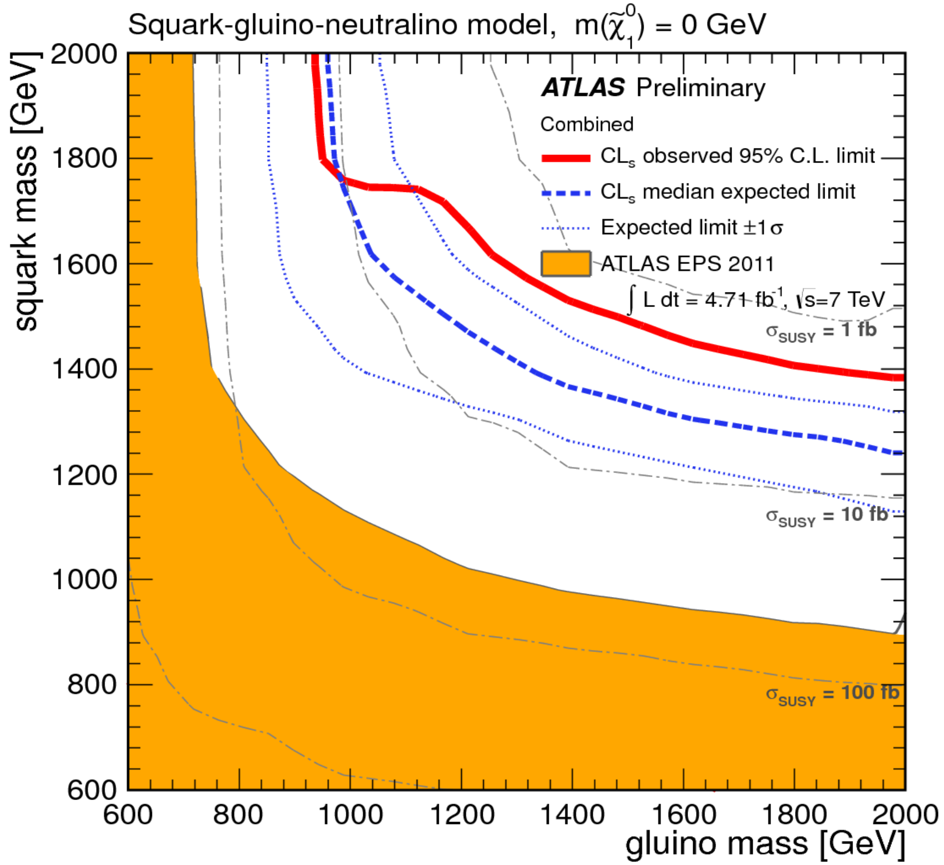
After fit:

	SR ≥ 2 jets	SR ≥ 3 jets	SR ≥ 4 jets	SR ≥ 5 jets	SR ≥ 6 jets
Total	$7 \pm 0.999 \pm 2.26$	$5.39 \pm 0.951 \pm 2.01$	$5.68 \pm 1.79 \pm 1.51$	$6.84 \pm 1.7 \pm 2.1$	$12.1 \pm 4.59 \pm 3.04$
Data	1	1	14	9	13
local p0 (Gaus. σ)	0.98(-2.1)	0.95(-1.7)	0.018(2.1)	0.29(0.55)	0.45(0.13)

0-lepton - Limits

- No significant excess observed with respect to SM predictions
- For each point the result from the signal region with best expected exclusion is shown





Limit for equal mass squarks & gluinos: ~ 1.4 TeV

0-lepton: multijets - 4.7 fb^{-1}

ATLAS-CONF-2012-037

- Search for gluino production in final states with several jets, E_T^{miss} , and no leptons, such as

$$\tilde{g}+\tilde{g}\rightarrow\left(t+\bar{t}+\tilde{\chi}_1^0\right)+\left(t+\bar{t}+\tilde{\chi}_1^0\right)$$

- Six non-exclusive signal regions:

Leptons (e, μ)	=0					
Jet p_T	>55 GeV			>80 GeV		
Jet $\lvert\eta\rvert$	<2.8					
Number of jets	≥ 7	≥ 8	≥ 9	≥ 6	≥ 7	≥ 8
$E_T^{miss}/\sqrt{H_T}$	>4 GeV$^{1/2}$					

Jet multiplicity/p_T motivated by trigger

No ΔR(jet,jet) cut! Large acceptance gain

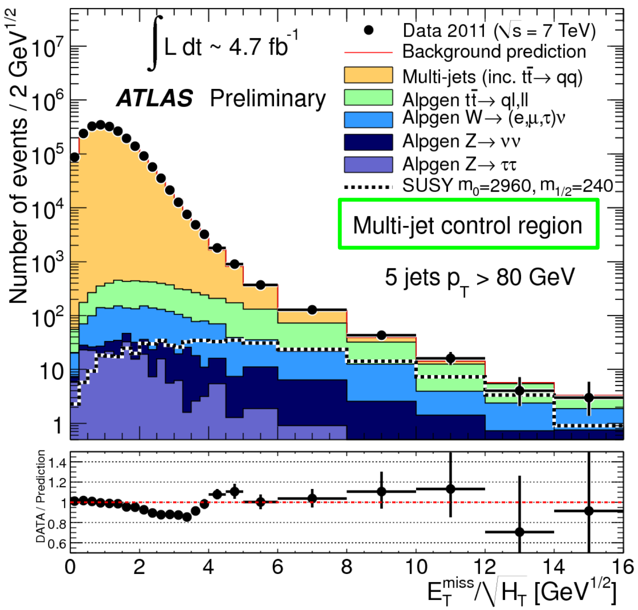
Designed for robust multi-jet background estimation

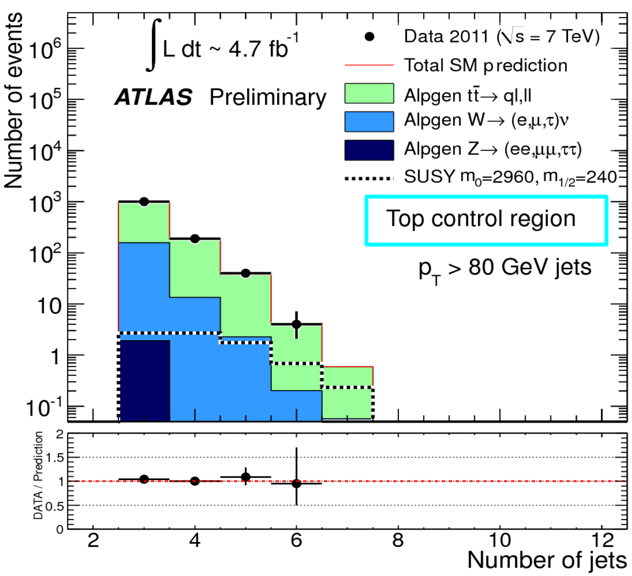
  - H_T scalar sum of the transverse momenta of all jets with pT > 40 GeV and |η| < 2.8
  - $\sqrt{H_T}$ correlated with E_T^{miss} resolution

- Main backgrounds from:
  - multi-jet processes (including fully hadr. tt), estimated from data in control regions with lower jet multiplicities and $E_t^{miss}/\sqrt{H_T}$
  - 'Leptonic': tt (semi and full-leptonic) and W/Z+jets, estimated from data (when possible) in control regions, and extrapolated to signal region using MC (similar to 0-lepton channel);

Update of previously published 1 fb^{-1} result: arXiv:1110.2299

0-lepton: multi-jets - Results

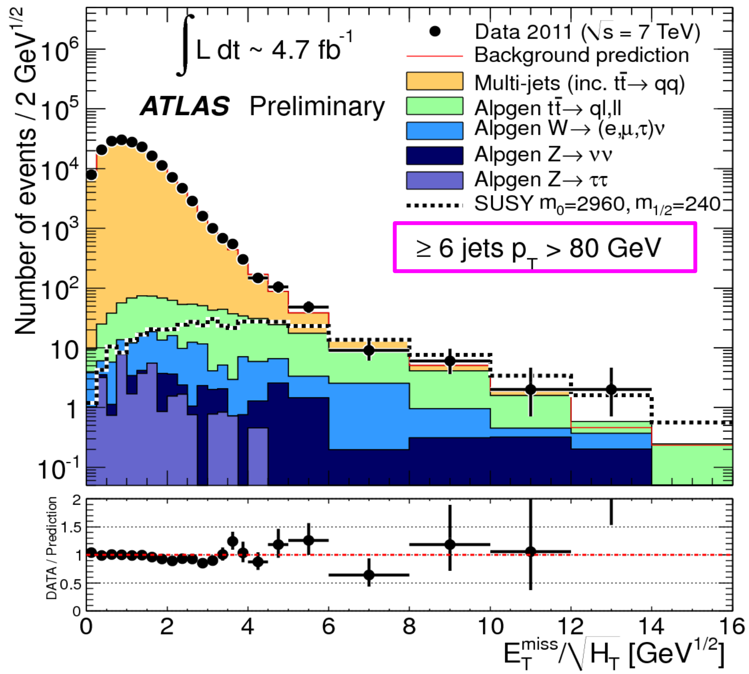




Multi-jet backgrounds

leptonic backgrounds

Signal region

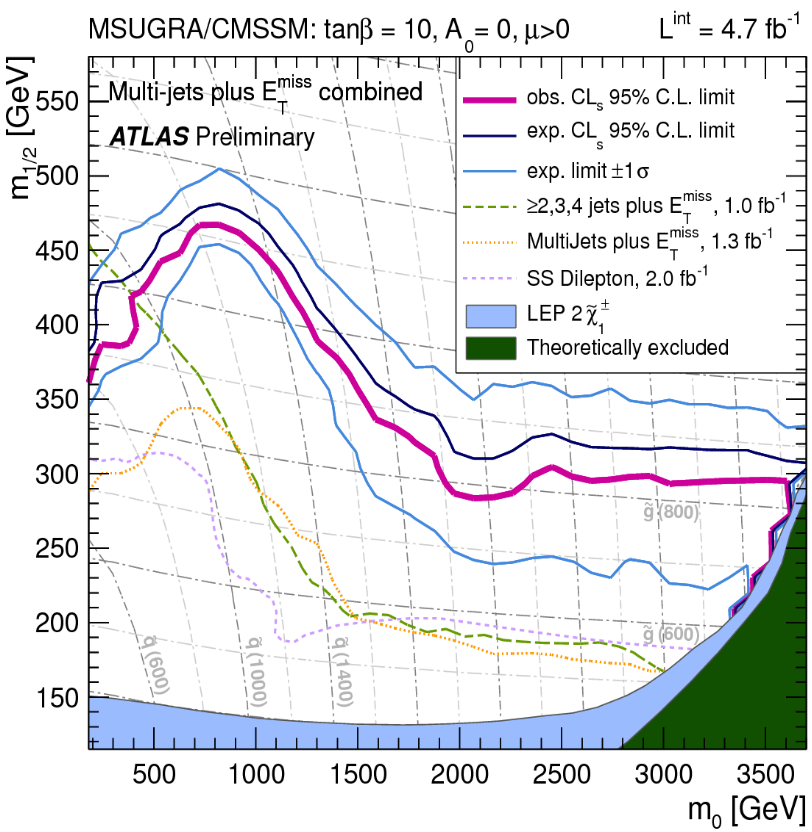


	≥ 7 jets	≥ 8 jets	≥ 9 jets	≥ 6 jets	≥ 7 jets	≥ 8 jets
Total Standard Model	**166±29**	**16.5±6.6**	**1.94±0.85**	**107±20**	**8.6±2.5**	**0.82±0.45**
Data	**154**	**22**	**3**	**106**	**15**	**1**
p_{SM}	0.65	0.25	0.28	0.51	0.07	0.43

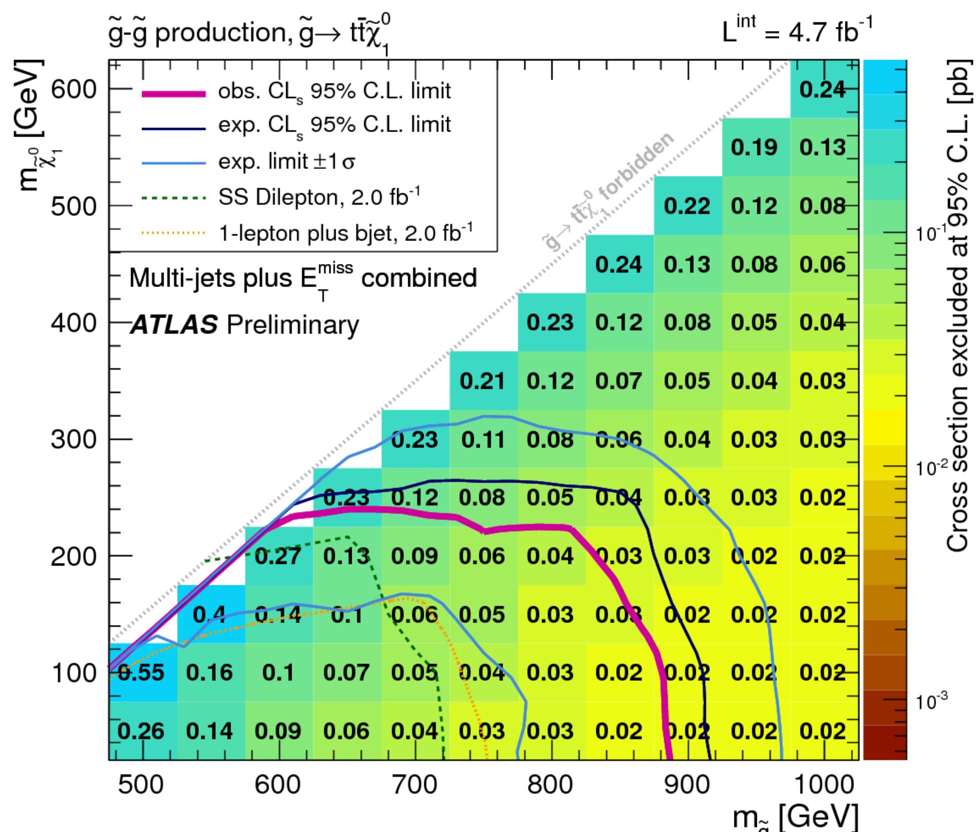
p_T > 55 GeV (≥ 7, ≥ 8, ≥ 9 jets) p_T > 80 GeV (≥ 6, ≥ 7, ≥ 8 jets)

0-lepton: multi-jet - Limits

- No significant excess observed with respect to SM predictions
- For each point the result from the signal region with best expected exclusion is shown



At large m0, gluino mass > 850 GeV



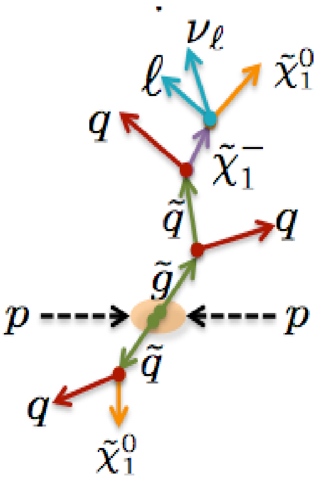
gluino mass > 880 GeV, for LSP mass < 100 GeV

1-lepton in a nutshell - 4.7 fb^{-1}

ATLAS-CONF-2012-038

- Search for strong production of squarks/gluinos pair in events containing jets, E_T^{miss}, and one isolated lepton (electron or muon) from chargino decay;

- **Orthogonal** signal regions, with:
  - One soft lepton to probe models with compressed spectra:
    - $7(6) < p_T < 25\ (20)$ GeV for electrons (muons)
  - One hard lepton to probe higher SUSY mass scales:
    - $p_T > 25\ (20)$ GeV for electrons (muons)
    - 2 exclusive signal regions: 3, 4 jets



- Signal/background discrimination provided by the effective mass m_{eff};

- Main backgrounds: multi-jet processes, W+jets , tt

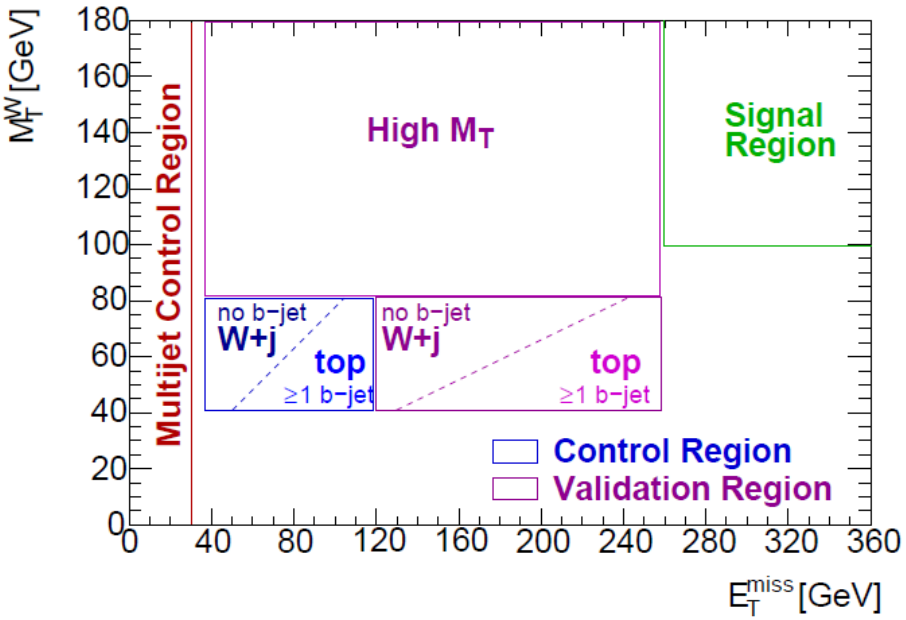
Update of previously published 1 fb^{-1} result: arXiv:1109.6572

1-lepton in a nutshell - 4.7 fb^{-1}

ATLAS-CONF-2012-038

- Background in signal regions from (over-constrained) simultaneous **fit** based on profile likelihood method;

- Fit inputs (poisson distributed):
  - Observed number of W+jets and tt in control regions (binned in jet multiplicities);
  - Transfer factors (TF) for W+jets and tt from MC, cross-contamination and signal contamination in control regions taken into account;
  - Number of multi-jet events in signal/control regions: entirely data-driven
  - Minor backgrounds in signal/control regions from MC.

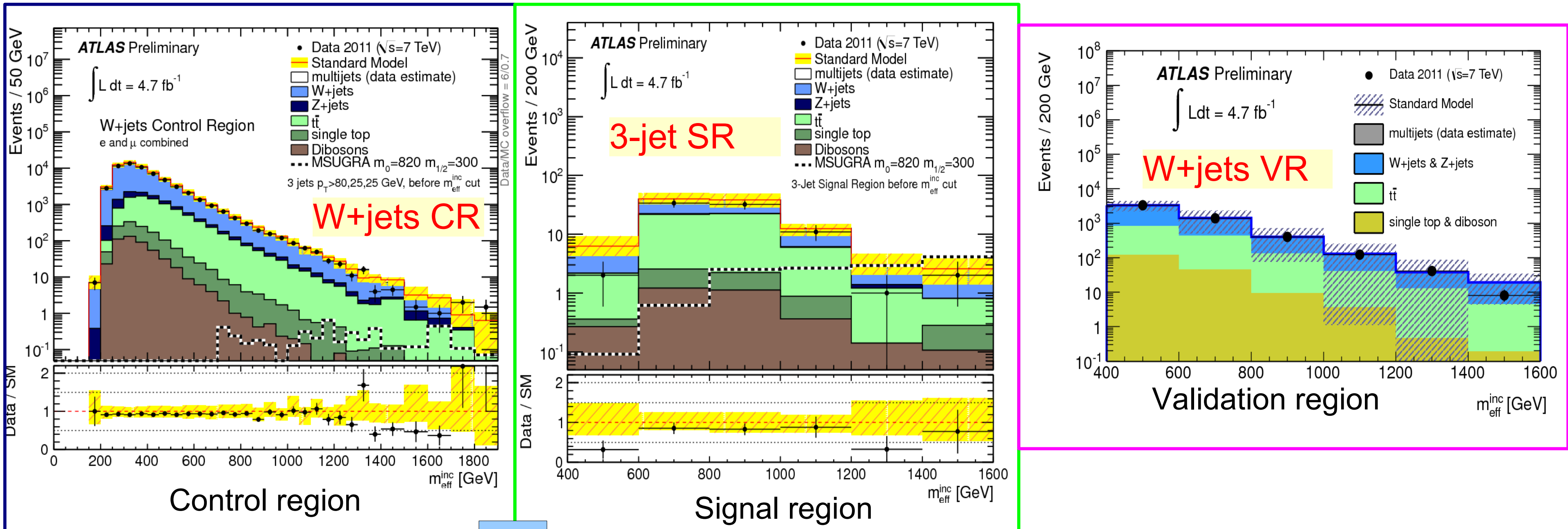


- Fit results are checked in validation regions, kinematically similar to signal regions;

- Fit free parameters: <u>overall</u> normalization for W+jets and tt;

- Uncertainties treated as nuisance parameters (gaussian distributed)

1-lepton - Results

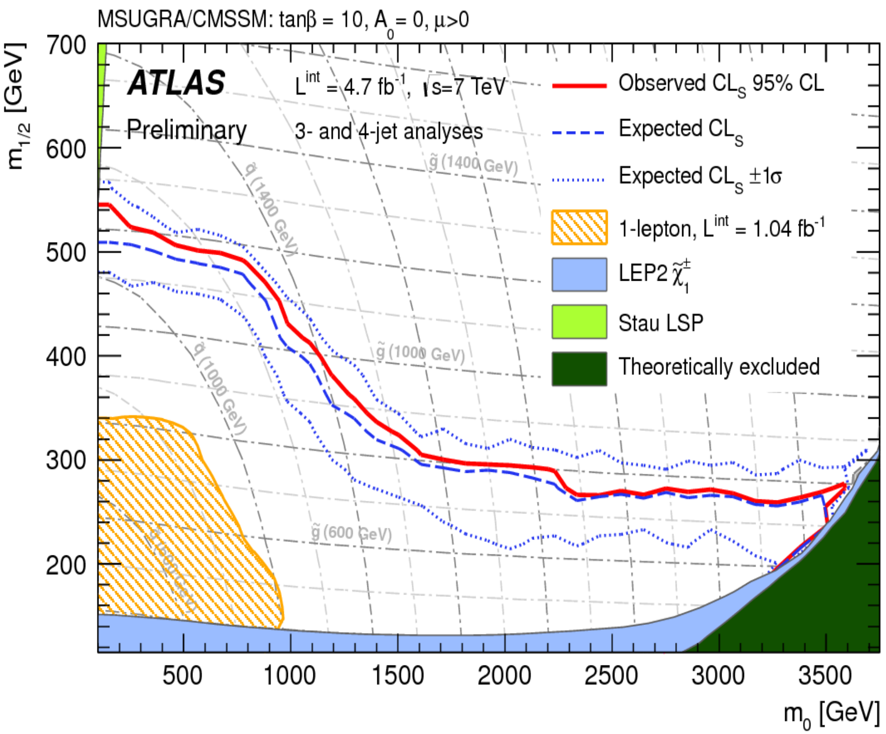


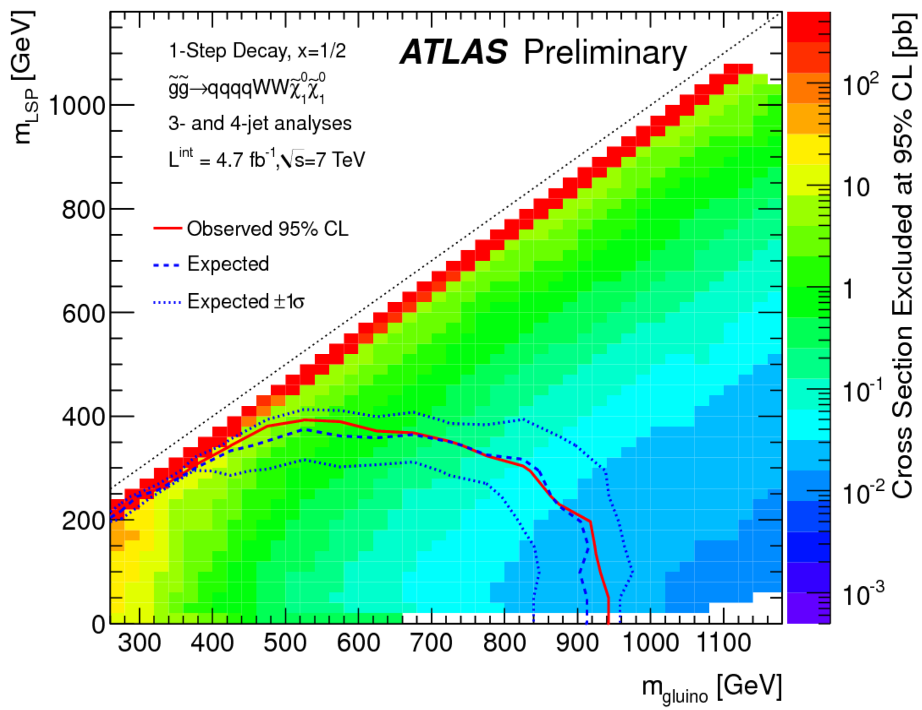
fit

	3-jet	4-jet	soft lepton
Observed events	3	6	26
Fitted bkg events	5.7 ± 4.0	8.3 ± 3.1	32 ± 11

1-lepton - Limits, hard lepton

- No significant excess observed with respect to SM predictions;
- Limits set using the m_{eff} **shape information** from fit (3- and 4-jet analyses combined).



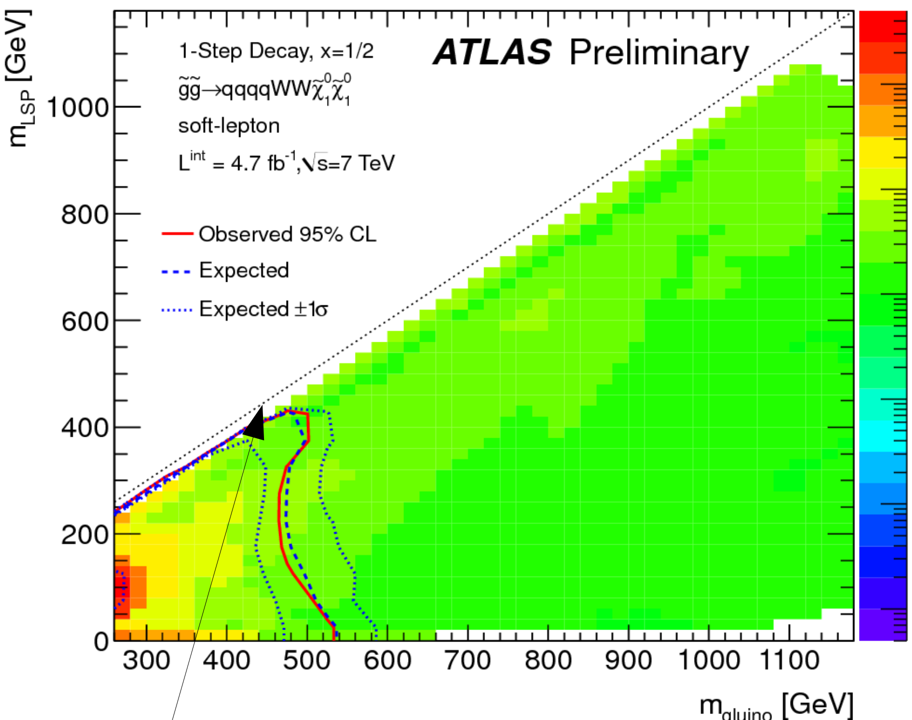


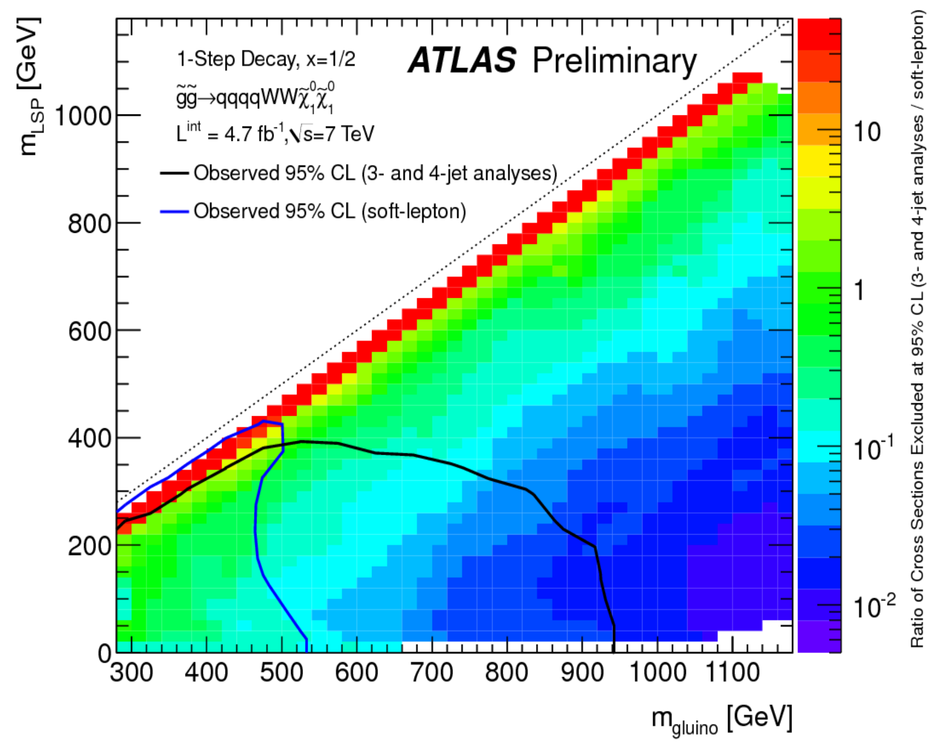
Limit for equal mass squarks & gluinos: ~ 1.2 TeV

gluino mass > 900 GeV, for LSP mass < 200 GeV

1-lepton - Limits, soft lepton

- No significant excess observed with respect to SM predictions
- Limits set using the m_{eff} **shape information** from fit





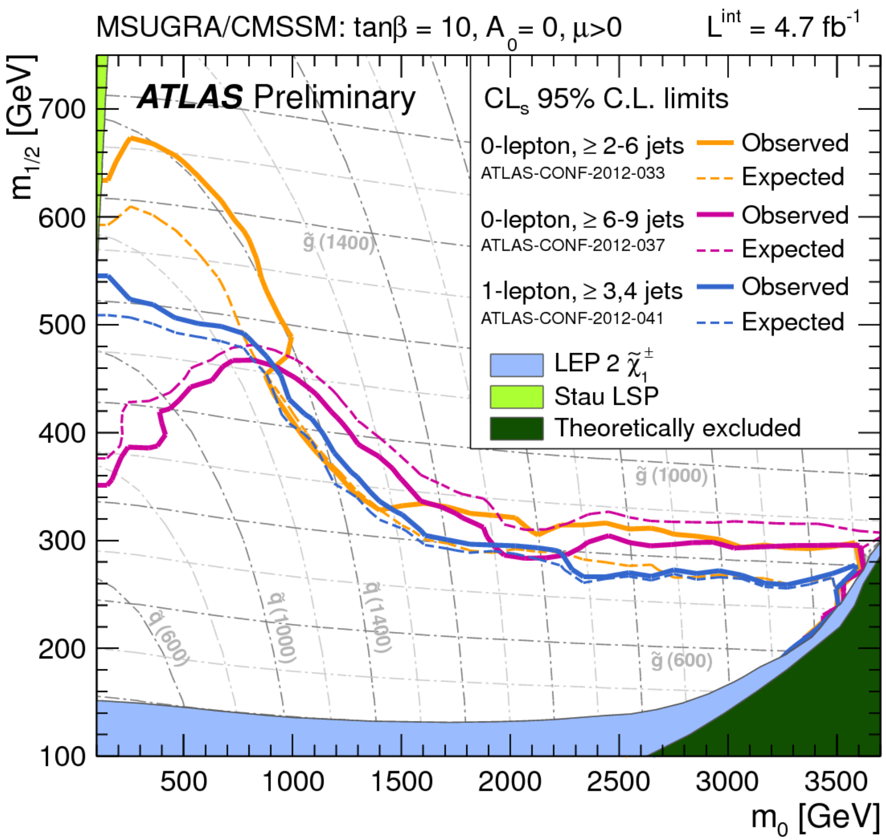
Gluino and LSP almost degenerate along the diagonal

Limits better by x20-30 on visible cross-section with respect to the hard lepton analyses

Conclusions

Search for strong production of SUSY particles in ATLAS using complementary analyses:

- 0- (+multi-jet) and 1-lepton results with full 2011 dataset (4.7 fb^{-1}), new signal regions to cover compressed spectra, limits further pushed!
- Many more analyses being updated, expect new results soon



- SUSY was not around the corner but still a long way to go to fully exploit the LHC search potential!
- Looking forward to analysing new LHC data @8TeV

Limit for equal mass squarks & gluinos: ~ 1.4 TeV

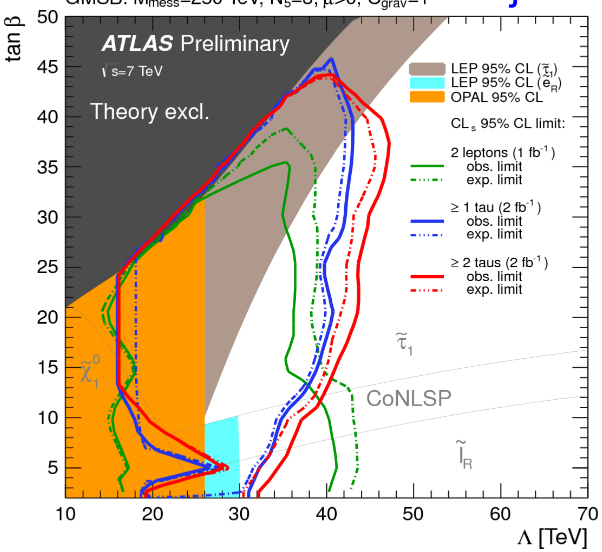
Spare slides

and that's NOT all folks!

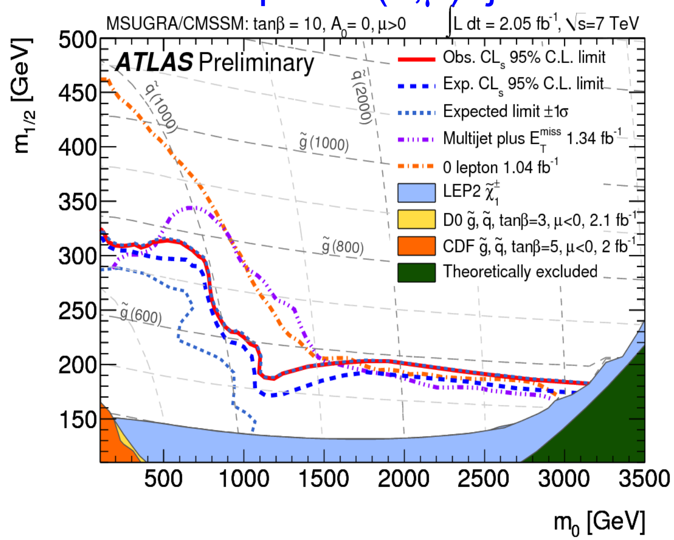
Analysis currently being updated to full 2011 dataset:

Di-photon + E_T^{miss}	(1.07 fb^{-1})	arXiv:1111.4116
Di-lepton + jets + E_T^{miss}	(1.04 fb^{-1})	arXiv:1110.6189
1 τ + jets + E_T^{miss}	(2.05 fb^{-1})	ATLAS-CONF-2012-005
$\geq$ 2 τ + E_T^{miss}	(2.05 fb^{-1})	ATLAS-CONF-2012-002
2 Same Sign leptons + jets + E_T^{miss}	(2.05 fb^{-1})	ATLAS-CONF-2012-004

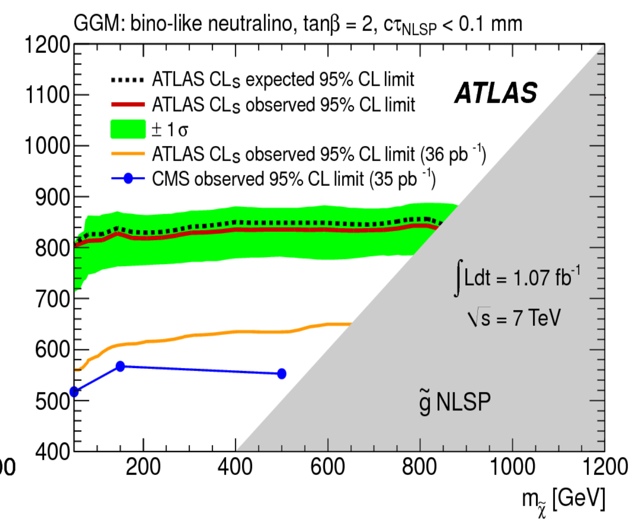
τs+jets



2 leptons (e,μ)+jets



2 photons



Stay tuned: *https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublic*

0-lepton - Object and event selection

- **Jets:** Candidates are reconstructed using the anti-kt jet clustering algorithm with a distance parameter of 0.4. These are calibrated using pT and eta-dependent calibration factors based on Monte Carlo corrections validated with extensive test-beam and collision-data studies. Only jet candidates with pT > 20 GeV are retained.
- **b-jets:** standard b-tagging algorithm based on neural networks, working point 60% efficiency
- **Electrons:** Candidates are required to have pT> 20 GeV, to have |eta| < 2.47, and to pass electron shower shape and track selection criteria.
- **Muons:** Candidates are required to have pT > 10 GeV and |eta| < 2.4.
- **Overlap removal:** Jets within R < 0.2 of an electron candidate are removed. Following this any lepton within R < 0.4 of a jet are removed.
- **Lepton Veto:** If any electron or muon candidate is left after overlap removal the event is vetoed.
- **Missing Transverse Energy:** muon candidates before overlap removal and calorimeter clusters with |eta| < 4.5 that are calibrated to physics objects that they are associated with. Clusters that are not associated with high pT physics objects are also included uncalibrated.
- **Event Cleaning:** A series of cuts are also applied to reduce the non-collision and detector noise backgrounds to a very low level.
- **Trigger:** 1 jet with pT > 75 GeV (EM scale) and $E_T^{miss} > 55$ GeV

0-lepton - Signal regions

Small mass splitting, rely on ISR

Requirement	Channel					
	A	A'	B	C	D	E
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] >	–	–	–	–	40	40
$p_T(j_6)$ [GeV] >	–	–	–	–	–	40
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$ >	0.4 ($i = \{1, 2, (3)\}$)			0.4 ($i = \{1, 2, 3\}$), 0.2 (p_T > 40 GeV jets)		
$E_T^{miss}/m_{eff}(Nj)$ >	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

To be in the trigger plateau region

Optimized to achieve maximal reach over ($m_{\tilde{q}}$,$m_{\tilde{g}}$) plane, and to enhance sensitivity to models with compressed spectra (SR A')

Longer decay chains

squark-squark, gluino-gluino, squark-gluino final states

- SRs are defined by the last cut on m_{eff} (incl.), which can be 'tight', 'medium' and 'loose'.

0-lepton - Fit results

Process	Signal Region					
	SRC loose	SRE loose	SRA medium	SRAp medium	SRC medium	SRE medium
$t\bar{t}$+SingleTop	74 ± 13 (75)	66 ± 26 (64)	7 ± 5 (5.1)	11 ± 3.4 (10)	12 ± 4.5 (10)	17 ± 5.8 (13)
Z/γ+jets	70 ± 22 (61)	22 ± 6.4 (13)	31 ± 9.9 (34)	64 ± 20 (69)	17 ± 5.9 (16)	8 ± 2.9 (4.4)
W+jets	62 ± 9.3 (61)	23 ± 11 (23)	19 ± 4.5 (21)	26 ± 4.6 (30)	8.1 ± 2.9 (11)	5.9 ± 3 (4.7)
QCD jets	0.39 ± 0.4 (0.16)	3.7 ± 1.9 (3.8)	0.14 ± 0.24 (0.13)	0 ± 0.13 (0.38)	0.024 ± 0.034 (0.013)	0.8 ± 0.53 (0.64)
Di-Bosons	7.9 ± 4 (7.9)	4.2 ± 2 (4.2)	7.3 ± 3.7 (7.5)	15 ± 7.4 (16)	1.7 ± 0.87 (1.7)	2.7 ± 1.3 (2.7)
Total	214 ± 24.9 ± 13	119 ± 32.6 ± 11.6	64.8 ± 10.2 ± 6.92	115 ± 19 ± 9.69	38.6 ± 6.68 ± 4.77	34 ± 4.47 ± 5.57
Data	210	148	59	85	36	25
local p0 (Gaus. σ)	0.55(-0.14)	0.21(0.8)	0.65(-0.4)	0.9(-1.3)	0.6(-0.26)	0.85(-1)

Process	Signal Region				
	SRA tight	SRB tight	SRC tight	SRD tight	SRE tight
$t\bar{t}$+SingleTop	0.22 ± 0.35 (0.046)	0.21 ± 0.33 (0.066)	1.8 ± 1.6 (0.96)	2 ± 1.7 (0.92)	3.9 ± 4 (2.6)
Z/γ+jets	2.9 ± 1.5 (3.1)	2.5 ± 1.4 (1.6)	2.1 ± 1.1 (4.4)	0.95 ± 0.58 (2.7)	3.2 ± 1.4 (1.8)
W+jets	2.1 ± 0.99 (1.9)	0.97 ± 0.6 (0.84)	1.2 ± 1.2 (2.7)	1.7 ± 1.5 (2.5)	2.3 ± 1.7 (1.5)
QCD jets	0 ± 0.0024 (0.002)	0 ± 0.0034 (0.0032)	0 ± 0.0058 (0.0023)	0 ± 0.0072 (0.021)	0.22 ± 0.25 (0.24)
Di-Bosons	1.7 ± 0.95 (2)	1.7 ± 0.95 (1.9)	0.49 ± 0.26 (0.51)	2.2 ± 1.2 (2.2)	2.5 ± 1.3 (2.5)
Total	7 ± 0.999 ± 2.26	5.39 ± 0.951 ± 2.01	5.68 ± 1.79 ± 1.51	6.84 ± 1.7 ± 2.1	12.1 ± 4.59 ± 3.04
Data	1	1	14	9	13
local p0 (Gaus. σ)	0.98(-2.1)	0.95(-1.7)	0.018(2.1)	0.29(0.55)	0.45(0.13)

1-lepton - Signal regions

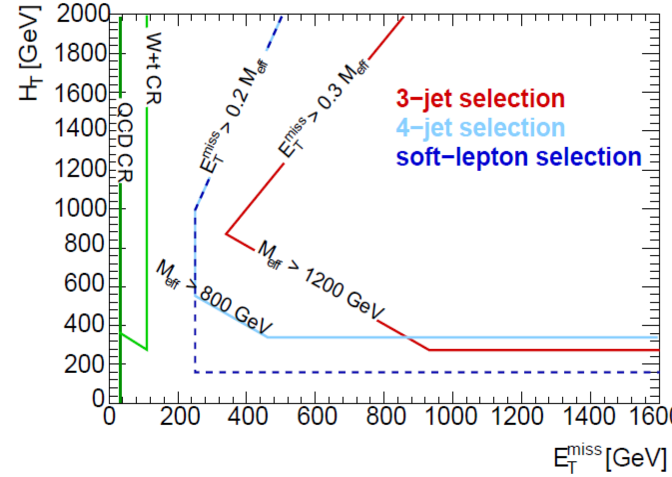
$H_T = M_{eff}^{inc} - E_T^{miss}$

	3-jet	4-jet	soft-lepton
Trigger	Single electron or muon (+jet)		Missing E_T
N_{lep}	== 1	== 1	== 1
p_T^{ℓ} (GeV)	> 25 (20)	> 25 (20)	[7,25] ([6,20])
$p_T^{\ell_2}$ (GeV)	< 10	< 10	< 7 (6)
N_{jet}	≥ 3	≥ 4	≥ 2
p_T^{jet} (GeV)	> 100, 25, 25	> 80, 80, 80, 80	> 130,25
$p_T^{jet\ 4}$ (GeV)	< 80	—	—
E_T^{miss} (GeV)	> 250	> 250	> 250
m_T (GeV)	> 100	> 100	> 100
E_T^{miss}/m_{eff}	> 0.3	> 0.2	> 0.3
m_{eff}^{inc} (GeV)	> 1200	> 800	—

Hard-lepton

Hard jet from ISR

Optimized to achieve maximal reach over ($m_{\tilde{q}}$,$m_{\tilde{g}}$) plane



Transverse mass:

$$M_T = \sqrt{2 p_T^{\ell} E_T^{miss} (1 - \cos(\Delta\phi(\vec{\ell}, \vec{P}_T^{miss})))}$$

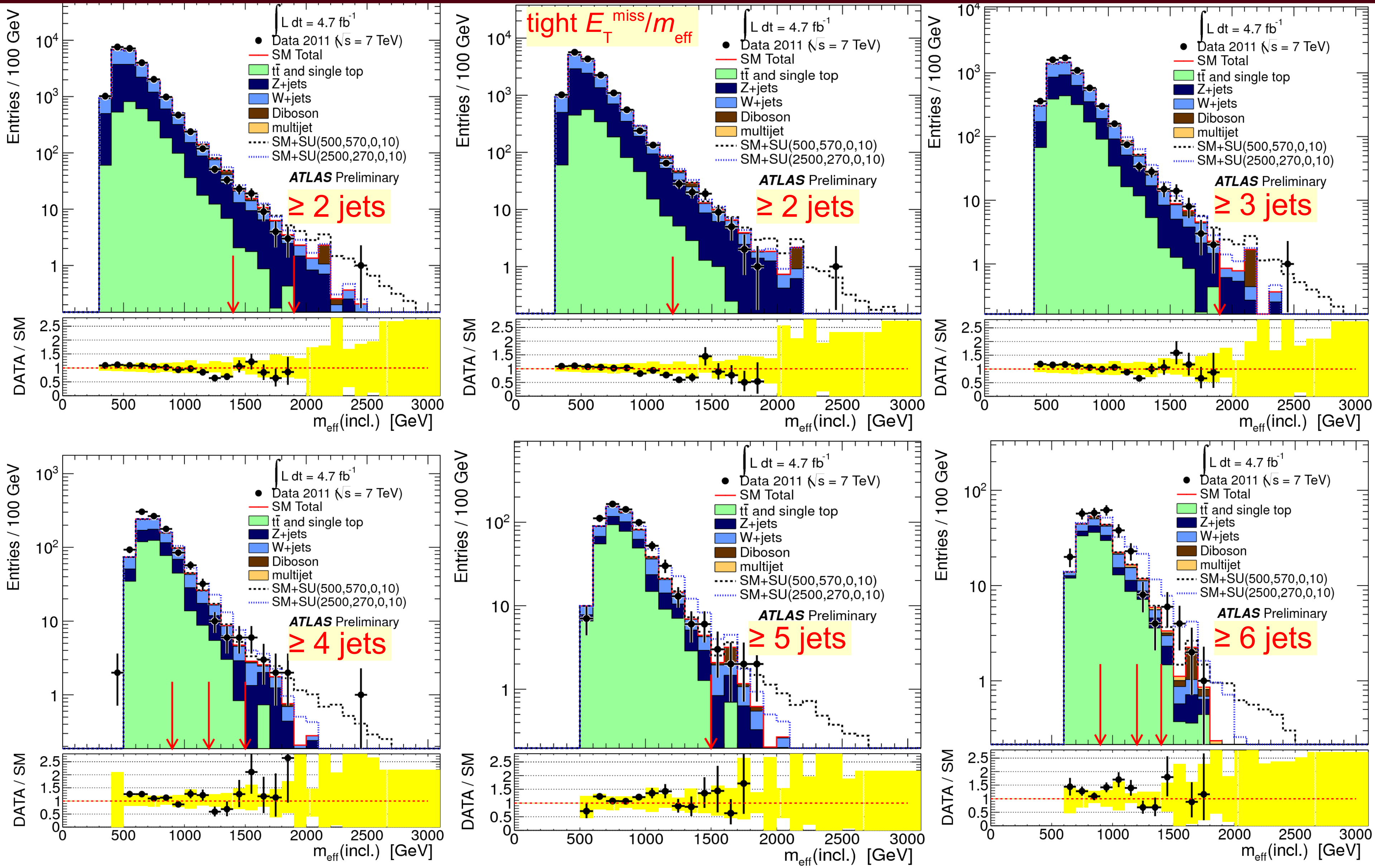
Effective mass:

$$M_{eff}^{inc} = p_T^{\ell} + \sum_{i=1} p_{T,i} + E_T^{miss}$$

lepton jets

- Sensitive to E_T^{miss} resolution as a function of calorimeter activity: E_t^{miss}/m_{eff};
- No cut on $\Delta\phi$(jet, E_t^{miss}) to increase sensitivity to decays with LSP boosted alongside the jet.

0-lepton - Results



0-lepton: multi-jets - Results