SUSY searches with ATLAS (focusing on R-parity conservation)

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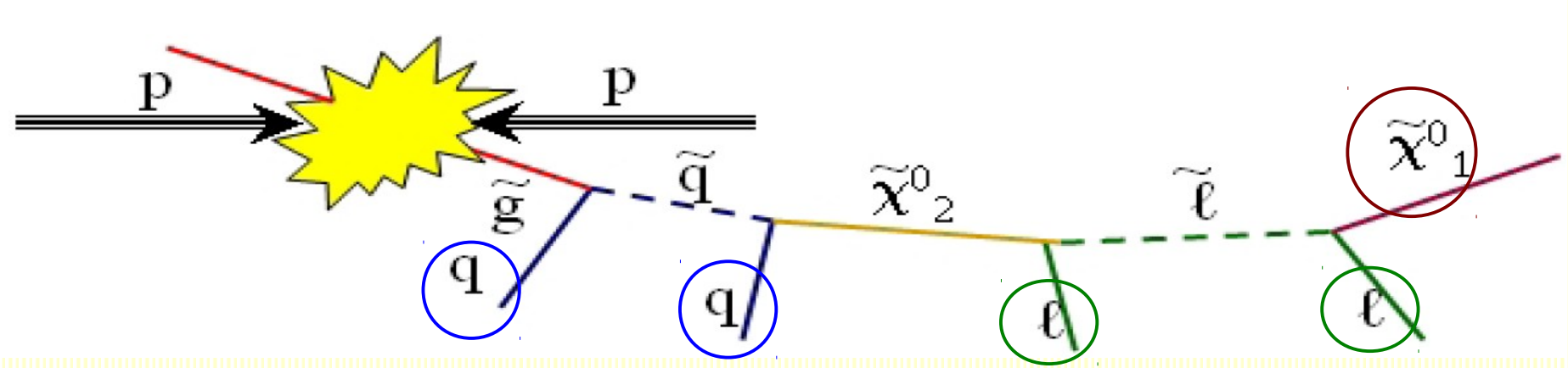
GDR Terascale, Marseille, 13.10.2011

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Typical signature



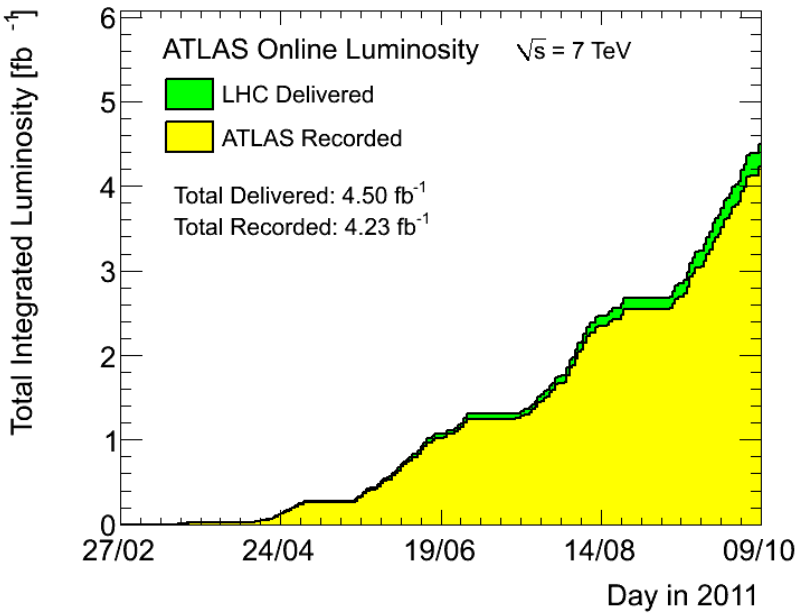
- Pair of gluinos/squarks produced by strong interactions
- Their decays give high-p_T jets and charginos/neutralinos
- Charginos/neutralinos decays can give leptons and the decay chain stops when the LSP is produced (R-parity conserving scenarios)
- The pair of stable LSP produced escapes the detector undetected leading to high transverse missing energy

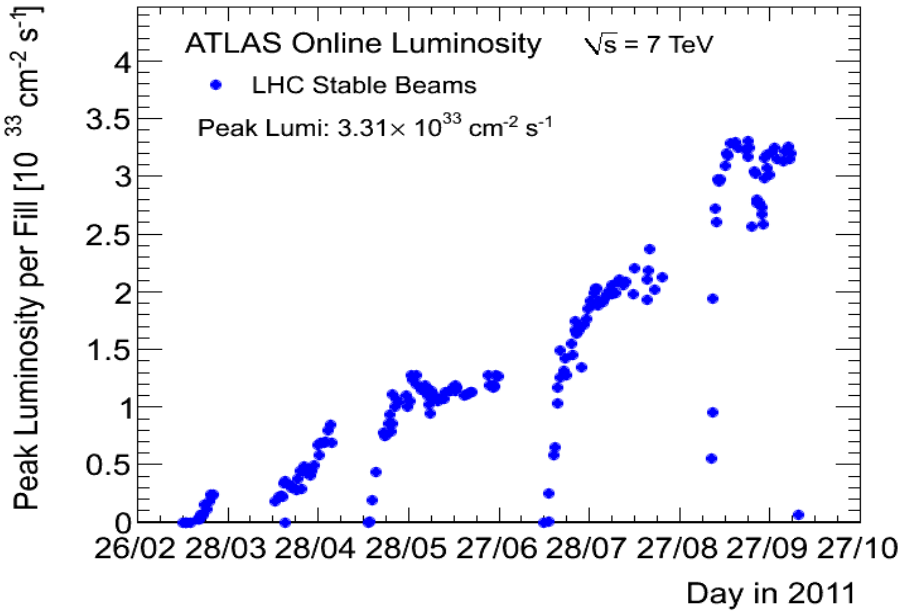
multi-Jets + n leptons + E_T^{miss}

Standard Model backgrounds (tt, W+jets, Z+jets, QCD jets and dibosons)

Data accumulated in 2011

- Excellent LHC performance





- Very good detector efficiency:

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.9	100	90.0	91.3	94.8	98.2	99.5	99.7	99.9	99.6	99.6	99.4

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and August 13th (in %). The inefficiencies in the LAr calorimeter will largely be recovered in the future.

ATLAS SUSY search results

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

2010 data

Short Title	Date	√s (TeV)	Lumi (pb^{-1})	Plots and Document	Journal
Search for displaced vertices arising from decays of new heavy particles in 7 TeV pp collisions at ATLAS	09/2011	7	33	arXiv:1109.2242, Plots+Aux. Material	Submitted to PLB
SUSY Search with Diphoton and Etmiss	07/2011	7	36	ArXiV:1107.0561, Plots+Aux. Material	**Accepted by EPJCL**
Search for Heavy Long-Lived Charged Particles	06/2011	7	37	ArXiV:1106.4495, Plots+Aux. Material	**PLB 703 (2011) 428**
Same-sign dilepton search with a simplified SUSY model	06/2011	7	35	ATLAS-CONF-2011-091, Plots+Aux. Material	No
Combined 0 and 1 lepton + jets + Etmiss searches	04/2011	7	35	ATLAS-CONF-2011-064, Plots+Aux. Material	No
SUSY Search with lepton pairs and Etmiss	03/2011	7	35	ArXiV:1103.6214, Plots+Aux. Material	**EPJC 71 (2011) 1682**
SUSY Search with identical flavour lepton pairs and Etmiss	03/2011	7	35	ArXiV:1103.6208, Plots+Aux. Material	**EPJC 71 (2011) 1647**
Search for an electron-muon resonance	03/2011	7	35	ArXiV:1103.5559, Plots+Aux. Material	**PRL 106 (2011) 251801**
SUSY Search with Etmiss and b-jets	03/2011	7	35	ArXiV:1103.4344, Plots+Aux. Material	**PLB 701 (2011) 398**
SUSY Searches with Multilepton, Jets and Etmiss	03/2011	7	34	ATLAS-CONF-2011-039, Plots+Aux. Material	No
Search for Stable Hadronising Squarks and Gluinos	03/2011	7	34	ArXiV:1103.1984, Plots+Aux. Material	**PLB 701 (2011) 1**
SUSY Search with jets and Etmiss	02/2011	7	35	ArXiV:1102.5290, Plots+Aux. Material	**PLB 701 (2011) 186**
SUSY Search with one lepton, jets, and Etmiss	02/2011	7	35	ArXiV:1102.2357, Plots+Aux. Material	**PRL 106 (2011) 131802**

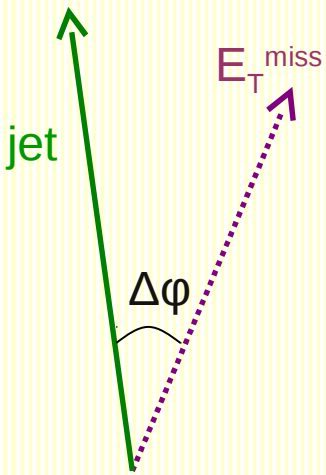
2011 data

Short Title	Date	√s (TeV)	Lumi (fb^{-1})	Plots and Document	Journal
✔ SUSY Search with one lepton, jets and Etmiss	09/2011	7	1.1	ArXiV:1109.6606, Plots+Aux. Material	Submitted to PRD
✔ SUSY Search with jets and Etmiss	09/2011	7	1.1	ArXiV:1109.6572, Plots+Aux. Material	Submitted to PLB
Search for an electron-muon resonance	09/2011	7	1.07	ArXiV:1109.3089, Plots+Aux. Material	Submitted to EPJCL
✔ SUSY Search with bjets, 1 lepton, and Etmiss	08/2011	7	1.03	ATLAS-CONF-2011-130, Plots+Aux. Material	No
✔ SUSY Search with bjets, and Etmiss	07/2011	7	0.83	ATLAS-CONF-2011-098, Plots+Aux. Material	No
SUSY Search with one lepton, jets, and Etmiss	06/2011	7	0.16	ATLAS-CONF-2011-090, Plots+Aux. Material	No
SUSY Search with jets and Etmiss	06/2011	7	0.16	ATLAS-CONF-2011-086, Plots+Aux. Material	No
✔ SUSY search with Large jet Multiplicity and Etmiss	10/2011	7	1.3	ArXiV:1110.2299, Plots+Aux. Material	Submitted to JHEP

✔ Discussed today

+ some preliminary results

Some useful variables



- $\Delta\phi(\text{jets}, E_T^{miss})$

  - Cutting on $\Delta\phi$ eliminates events in which E_t^{miss} is closely related to one of the leading jets (QCD)

- Effective mass m_{eff} (scalar sum of sel. jets & leptons p_T and E_T^{miss})

  - peaks at a value which is correlated with the mass of the pair of SUSY particles produced in the *pp* interaction

- The transverse mass m_T $m_{\mathrm{T}}^2 \equiv 2|\mathbf{p}_{\mathrm{T}}^{\ell}||E_{\mathrm{T}}^{\mathrm{miss}}| - 2\mathbf{p}_{\mathrm{T}}^{\ell} \cdot \vec{E}_{\mathrm{T}}^{\mathrm{miss}}$

  - useful to remove BG in which a W decays leptonically

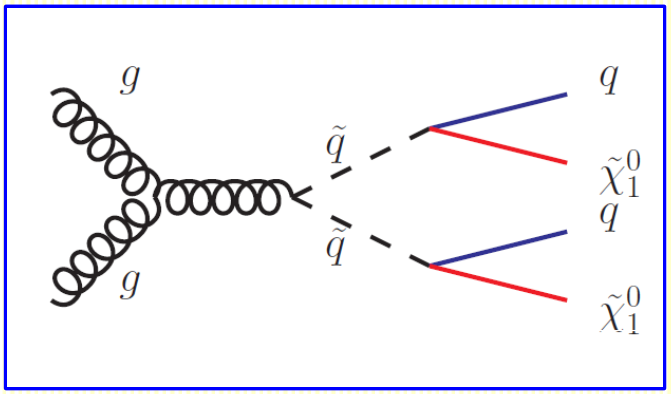
The 0-lepton channel

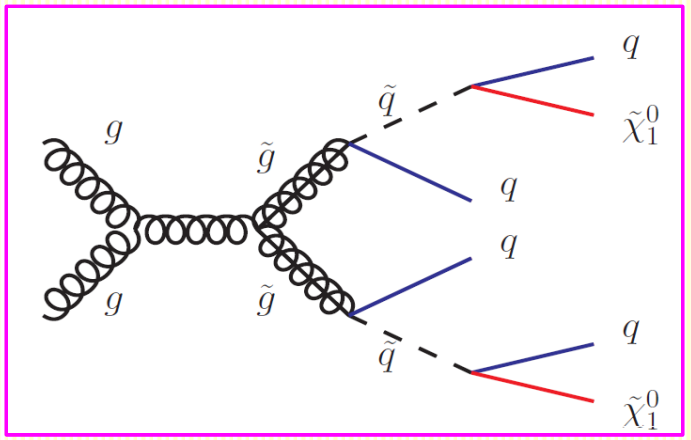
Select events with jets, missing transverse momentum and no lepton (veto e/μ)

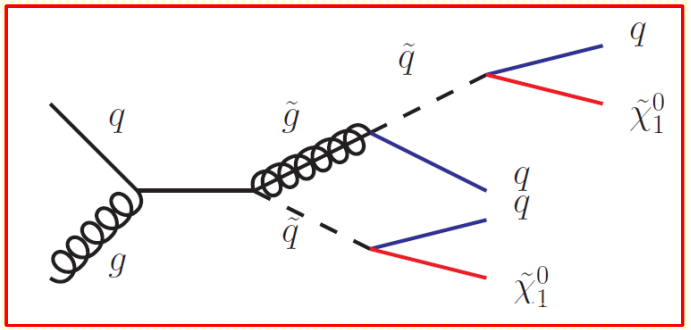
arXiV:1109.6572
submitted to PLB

Defining the signal regions

Signal Region	≥ 2-jet	≥ 3-jet	≥ 4-jet	High mass
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 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
$\Delta\phi(\mathrm{jet}, \vec{P}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100







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$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100

Trigger requirements

Reject the QCD BG

Optimize for SUSY

Main backgrounds

Z+jets: $\nu\nu$ decay

W+jets: $\tau\nu$ decay or missed e/μ

Top pair production: τ decay of a W

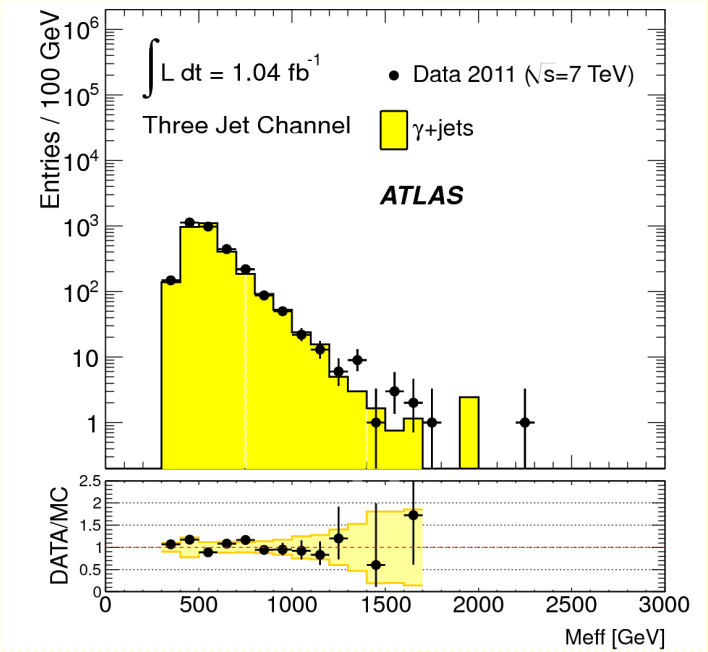
QCD multijets

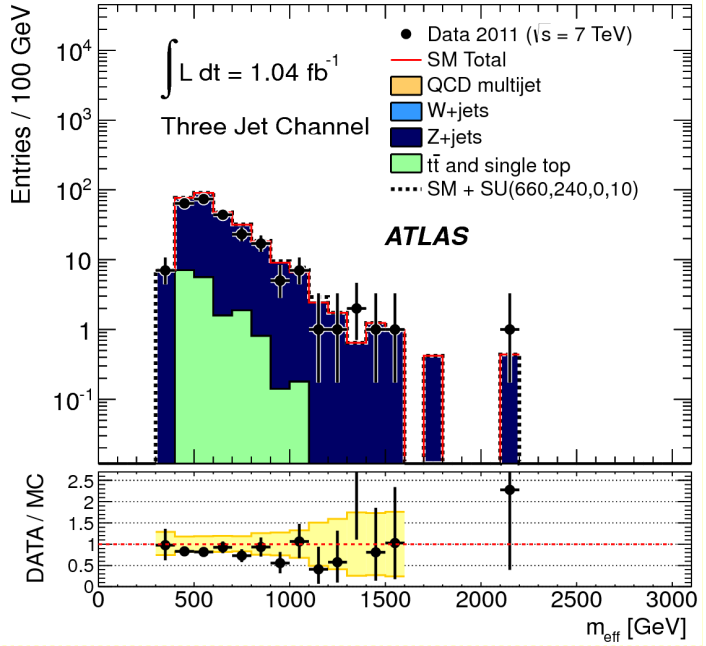
- Evaluate each BG in a control region (5 CRs x 5 SRs)

- Extrapolate from the CR to the SR with a transfer factor

- Profile likelihood fit (correlated systematic uncertainties and CR cross-contamination)

Z+jets BG



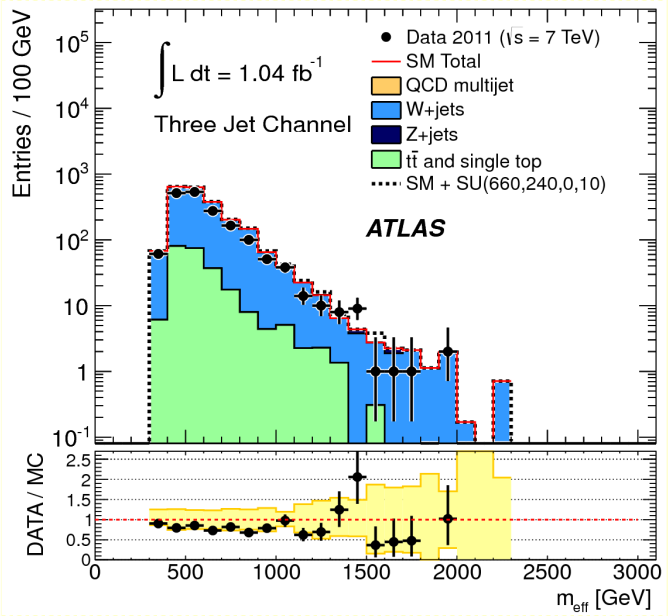


Two control regions are used:

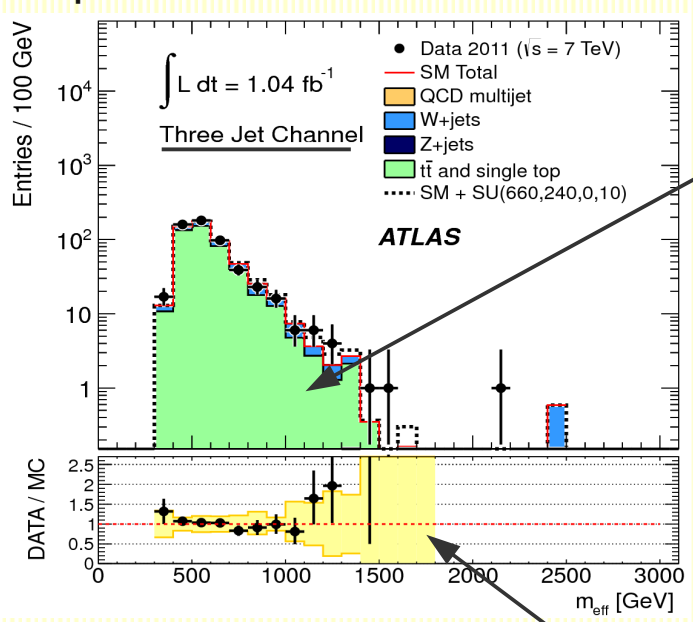
- γ + jets, where the photon is added the the E_T^{miss}
- Z($\rightarrow$ll)+jets, where the leptons are removed ($\rightarrow$ E_T^{miss})

W+jets and top BG

W CR



Top CR



MC normalized to luminosity

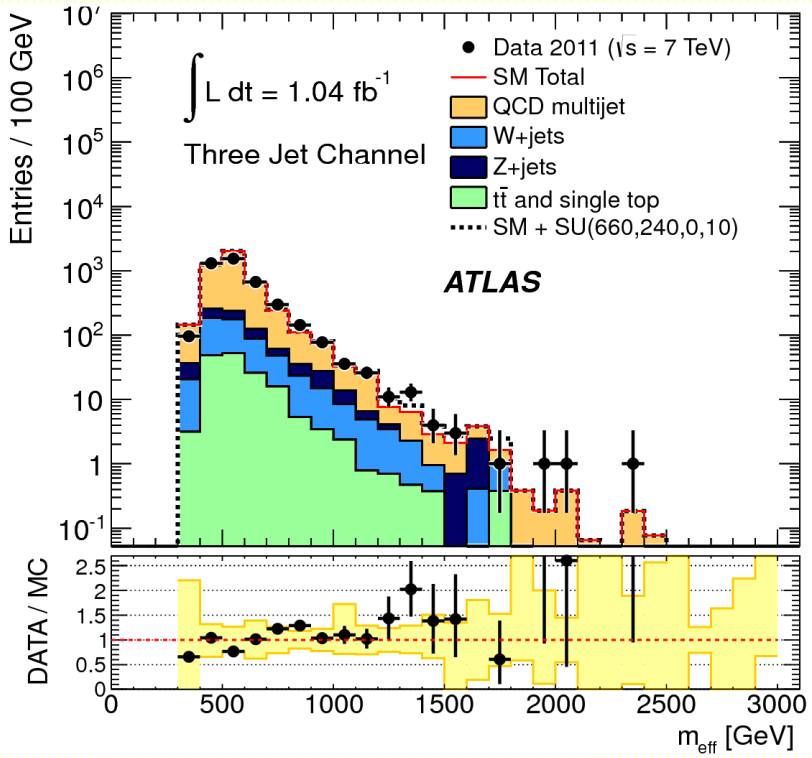
JES, JER, MC stat uncert.

- Select 1-lepton events with $30 < m_T < 100$ GeV

- Split the top from W by asking for no b-tagged jet (W) or at least one b-tagged jet (top)

- Treat the lepton as a jet (for MET calculations, Meff, jet cuts...)

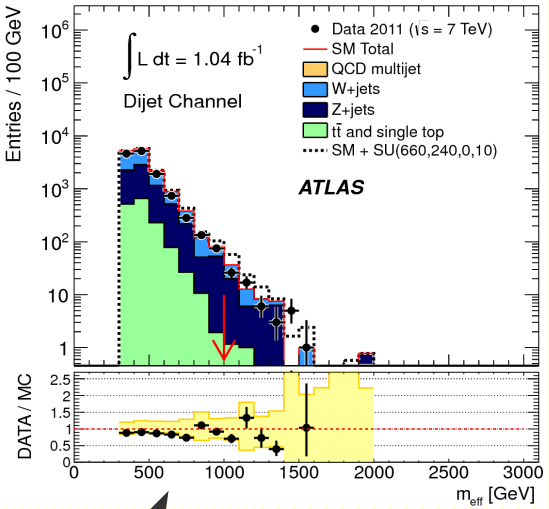
QCD BG

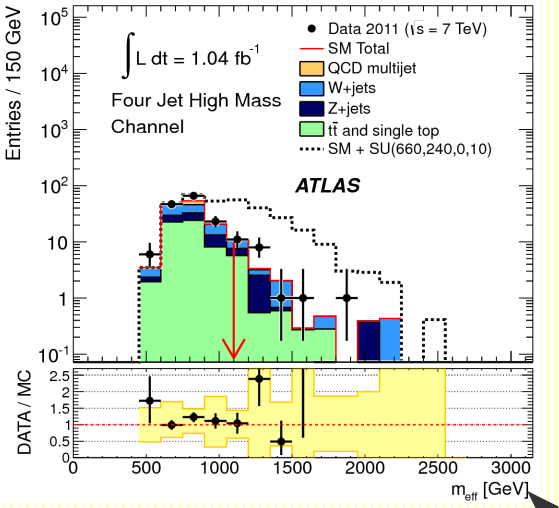


Data-driven background estimation:

- Reverse and tighten the cut: $\Delta\varphi(\text{jet}, E_T^{miss})_{min} < 0.2$
- Transfer factor computed using pseudo-events obtained by smearing low-E_T^{miss} events with the jet response function

Results

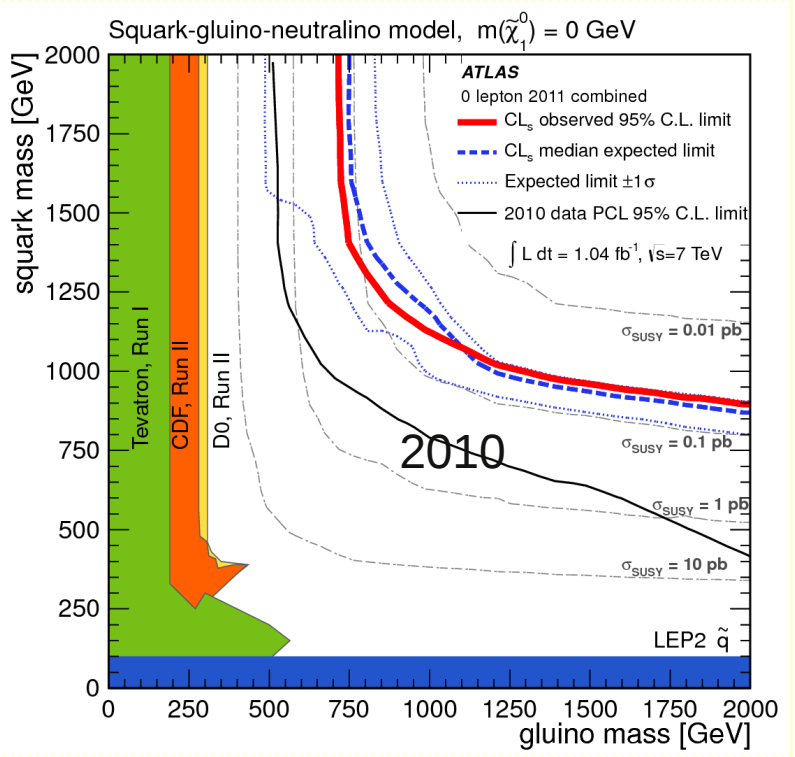


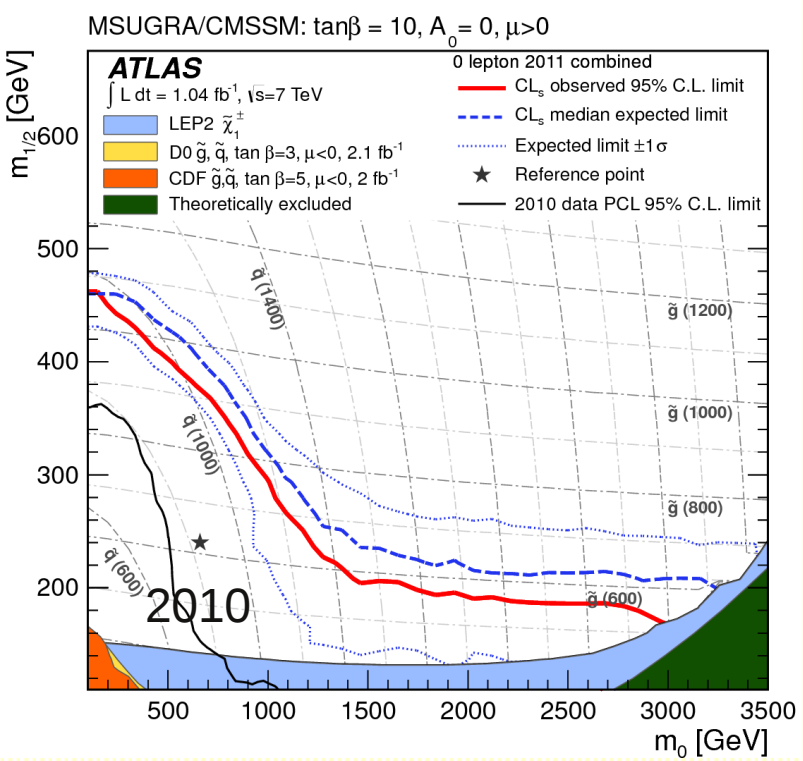


Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, m_{eff} > 500 GeV	≥ 4-jet, m_{eff} > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
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

95% CL limits on cross section · acceptance · efficiency:
22 fb, 25 fb, 429 fb, 27 fb and 17 fb

Exclusion plot





→ gluino and squark masses below 700 GeV and 875 GeV are excluded (for squark or gluino masses below 2 TeV)

→ limit at 1075 GeV for equal mass squarks and gluinos

→ equal mass squarks and gluinos are excluded below 950 GeV

parameters at GUT scale

1. Unified gaugino(scalar) mass $m_{1/2}(m_0)$
3. Ratio of H_1, H_2 vevs $\tan\beta$
4. Trilinear coupling A_0
5. Higgs mass term $\mathrm{sgn}(\mu)$

The 1-lepton channel

Select events with jets, missing transverse momentum and exactly one lepton (e/μ)

arXiV:1109.6606
Submitted to PRD

Defining the signal region

The isolated one-lepton requirement suppresses QCD multijet and allows a lepton-based trigger

- Exactly one lepton (e/μ) with pT>20 GeV

Event Selection in SRs	3JL	3JT	4JL	4JT
Leading jet p_T [GeV]	60	80	60	60
Subsequent jets p_T [GeV]	25	25	25	40
M_T [GeV]	100	100	100	100
E_T^{miss} [GeV]	125	240	140	200
E_T^{miss}/M_{eff}	0.25	0.15	0.30	0.15
M_{eff} [GeV]	500	600	300	500

$\Delta\phi$ (jet, E_t^{miss}) >0.2

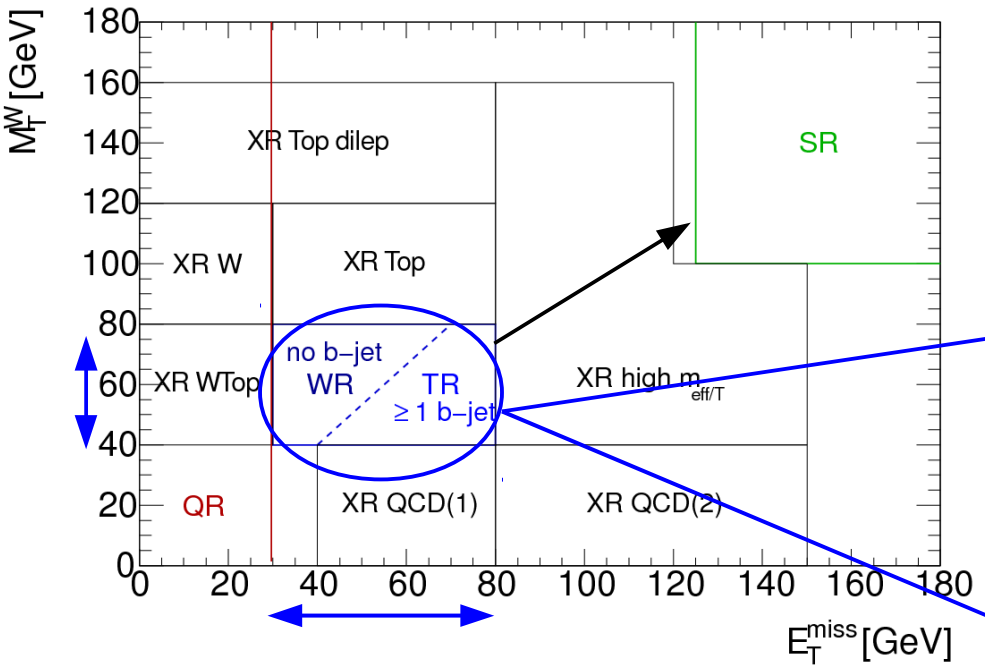
gluino/squark cascade decay with intermediate steps

Suppresses W+jets and tt

Reduce the QCD BG further

Optimize for SUSY

Main backgrounds: W+jets and tt



$$\underbrace{N(\bar{t}t \text{ pred., } SR)}_{\text{predicted events in signal region}} = \underbrace{(N(\text{fitted } \bar{t}t(\text{data}), CR))}_{\text{measured events in control region - other BG}} \times \underbrace{\frac{N(\bar{t}t(MC), SR)}{N(\bar{t}t(MC), CR)}}_{\text{extrapolation factor CR to SR}}$$

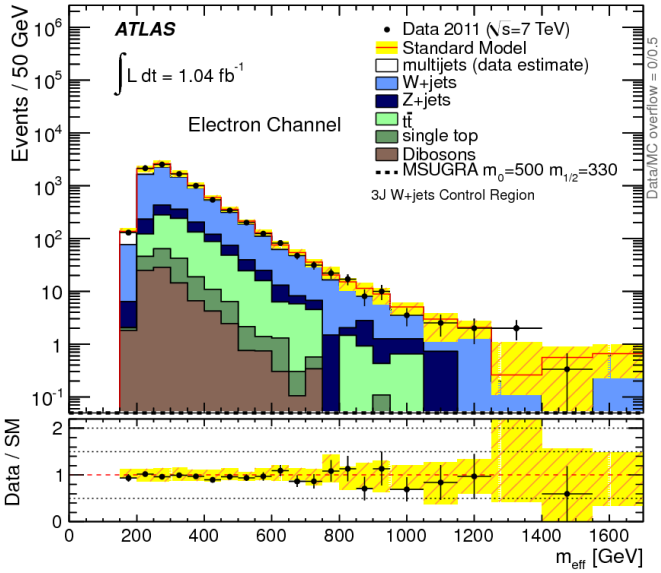
③ ① ②

From data

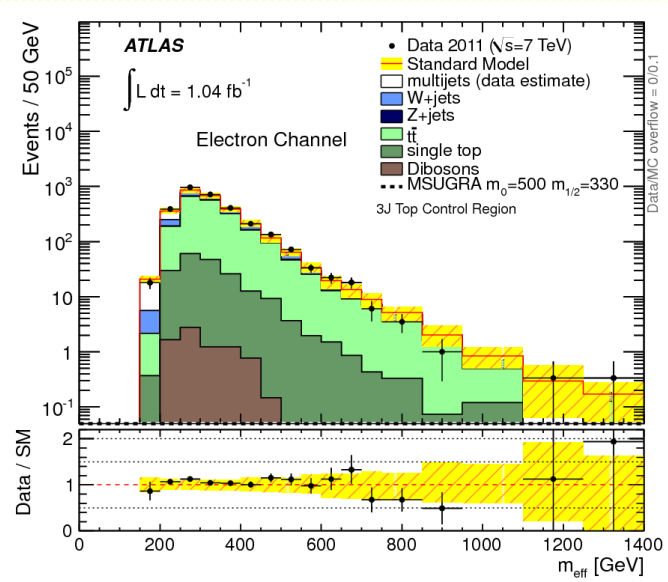
From MC

Method cross-checked with additional control regions

W control region: no b-jet



Top control region: ≥ 1 b-jet



QCD BG

Evaluated using the 'matrix method' which plays on the difference in isolation between the leptons in QCD events with respect to signal leptons

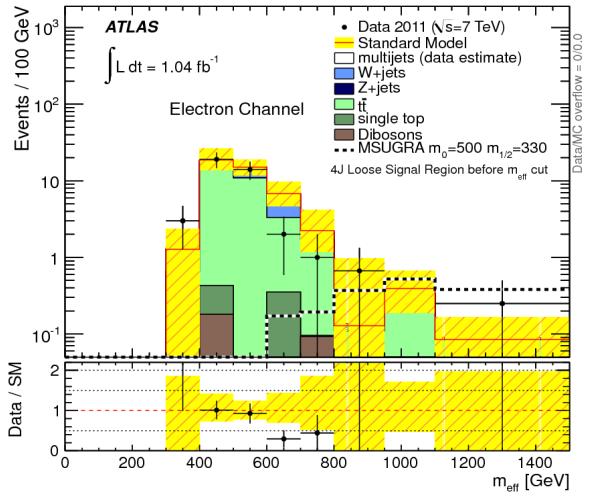
- ***Loose*** control sample with isolation criteria relaxed with respect to the ***tight*** SUSY selections
- Define two categories: QCD leptons (***Q***) and non-QCD leptons (***Ø***)
– ε is the probability that a loose lepton is also tight

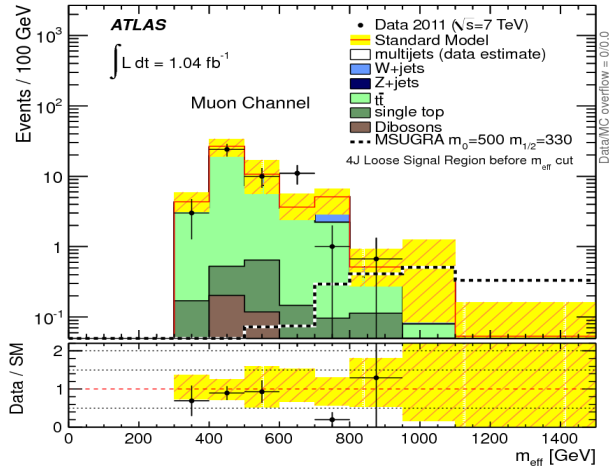
$$N^{obs}_{tight} = N^{\not Q}_{tight} + N^{Q}_{tight}$$

$$N^{obs}_{loose\ not\ tight} = \left(1/\epsilon_{\not Q} - 1\right) N^{\not Q}_{tight} + \left(1/\epsilon_{Q} - 1\right) N^{Q}_{tight}$$

The quantities in red are measured: solve the equations and extract the number of QCD events

Results





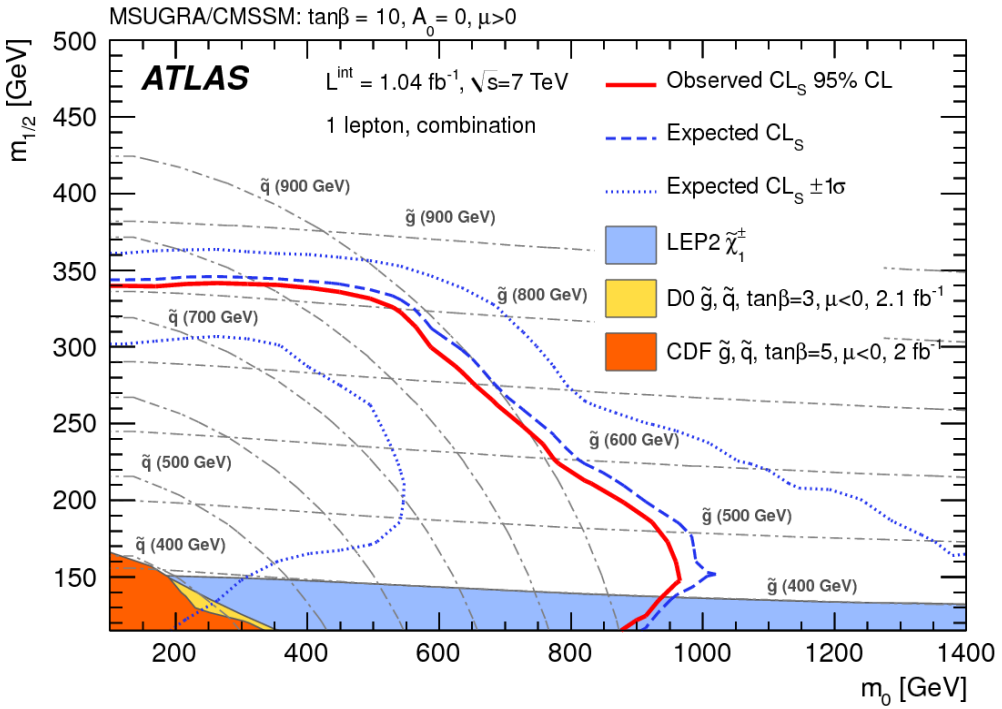
Electron channel	$\langle\epsilon\sigma\rangle_{\rm obs}^{95}$ [fb]
3JL	50
3JT	14
4JL	33
4JT	10

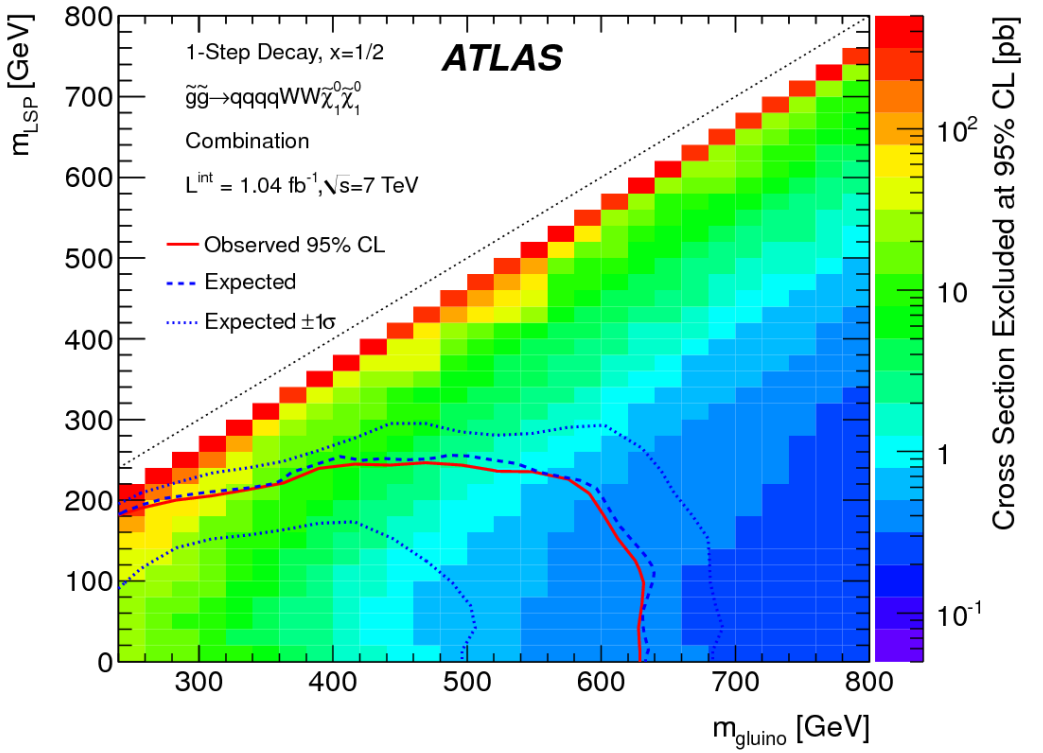
Muon channel	$\langle\epsilon\sigma\rangle_{\rm obs}^{95}$ [fb]
3JL	36
3JT	10
4JL	31
4JT	9

Electron channel	3JL Signal region	3JT Signal region	4JL Signal region	4JT Signal region
Observed events	71	14	41	9
Fitted top events	56 ± 20 (51)	7.6 ± 3.0 (6.8)	38 ± 15 (34)	4.5 ± 2.6 (4.1)
Fitted W/Z events	35 ± 20 (34)	10.5 ± 6.5 (10.1)	9.5 ± 7.5 (9.2)	3.5 ± 2.2 (3.4)
Fitted multijet events	$6.0^{+2.3}_{-1.4}$	$0.46^{+0.37}_{-0.22}$	$0.90^{+0.54}_{-0.37}$	$0.00^{+0.02}_{-0.00}$
Fitted sum of background events	97 ± 30	18.5 ± 7.4	48 ± 18	8.0 ± 3.7

Muon channel	3JL Signal region	3JT Signal region	4JL Signal region	4JT Signal region
Observed events	58	11	50	7
Fitted top events	47 ± 16 (38)	8.9 ± 3.2 (7.3)	39 ± 13 (36)	4.7 ± 2.2 (4.3)
Fitted W/Z events	16.6 ± 9.4 (20.1)	5.0 ± 3.2 (6.1)	14.1 ± 8.5 (14.2)	1.4 ± 1.1 (1.4)
Fitted multijet events	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$	$0.0^{+0.0}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Fitted sum of background events	64 ± 19	13.9 ± 4.3	53 ± 16	6.0 ± 2.7

Exclusion plot





Exclude $m_{gluino} = M_{squark} < 875$ GeV

Limits also provided for simplified models: 1-step gluino (squark) decay and x= ¼, ½ , ¾ where $x=(m_{\chi\pm}-m_{\chi 0})/(m_{squark,gluino}-m_{\chi 0})$

Color coding: Cross section limit,

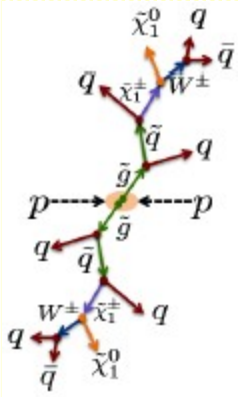
Full line: Obs. Excl. limit for 100% BR to assumed decay mode

Quickly, more summer results

Multijets

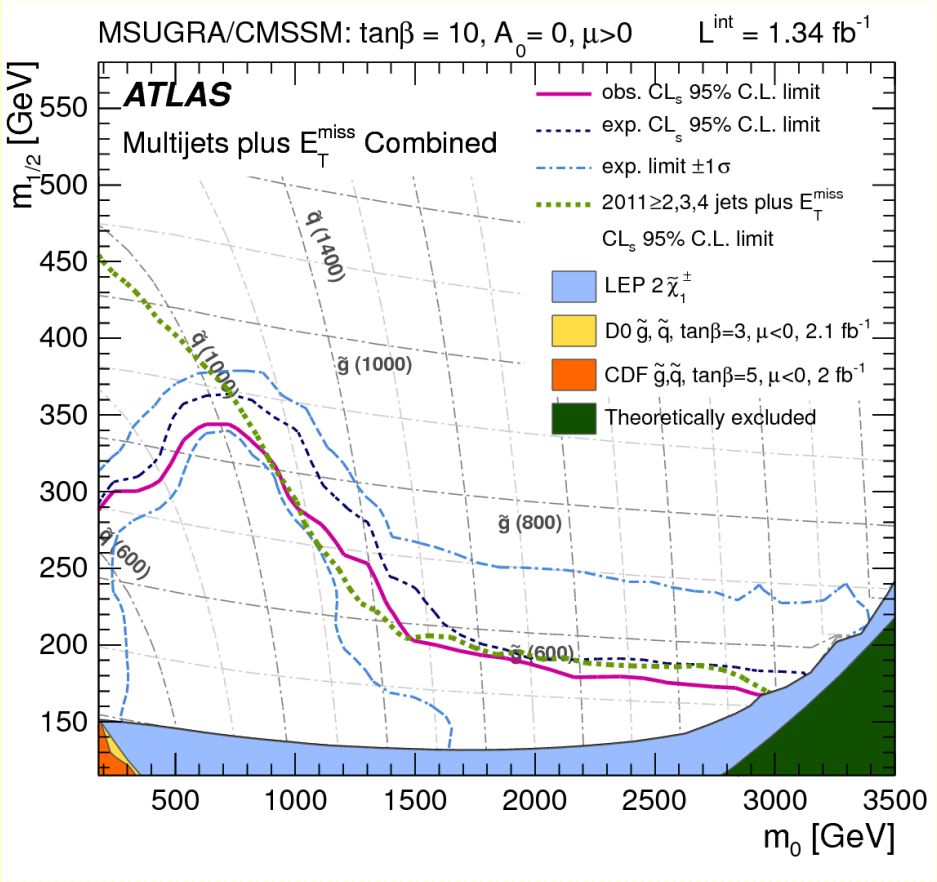
On the arXiv since yesterday!

ArXiV:1110.2299, submitted to JHEP



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
$E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{H_T}$	> 3.5 GeV$^{1/2}$			

Signal region	7j55	8j55	6j80	7j80
Multi-jets	26 ± 5.2	2.3 ± 0.7	19 ± 4	1.3 ± 0.4
$t\bar{t} \to q\ell, \ell\ell$	10.8 ± 6.7	$0^{+4.3}$	6.0 ± 4.6	$0^{+0.13}$
W + jets	0.95 ± 0.45	$0^{+0.13}$	0.34 ± 0.24	$0^{+0.13}$
Z + jets	$1.5^{+1.8}_{-1.5}$	$0^{+0.75}$	$0^{+0.75}$	$0^{+0.75}$
Total Standard Model	39 ± 9	$2.3^{+4.4}_{-0.7}$	26 ± 6	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3
$N^{95\%}_{\mathrm{BSM,max}}$	26.0	11.2	16.3	6.0
$\sigma^{95\%}_{\mathrm{BSM,max}} \times \epsilon$/fb	19.4	8.4	12.2	4.5
p_{SM}	0.30	0.36	0.49	0.16



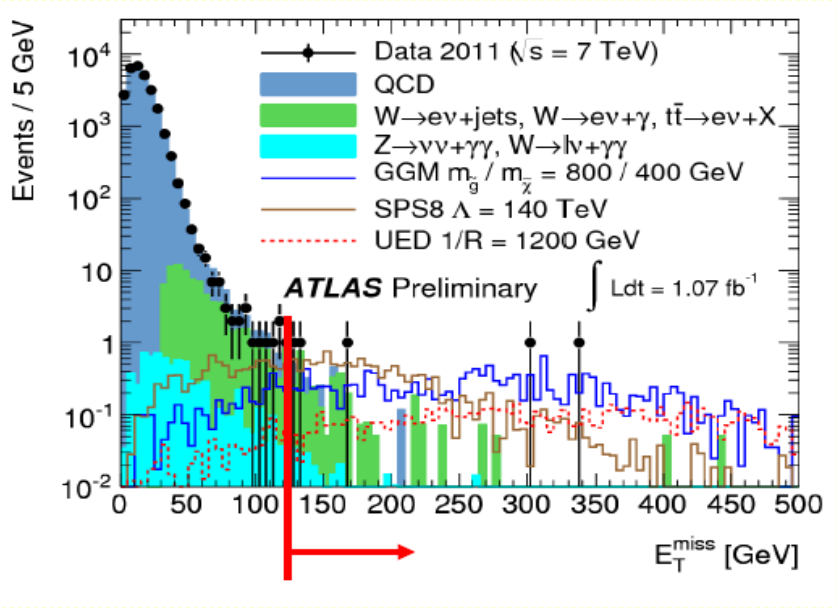
Quickly, more summer results

Di-photon searches

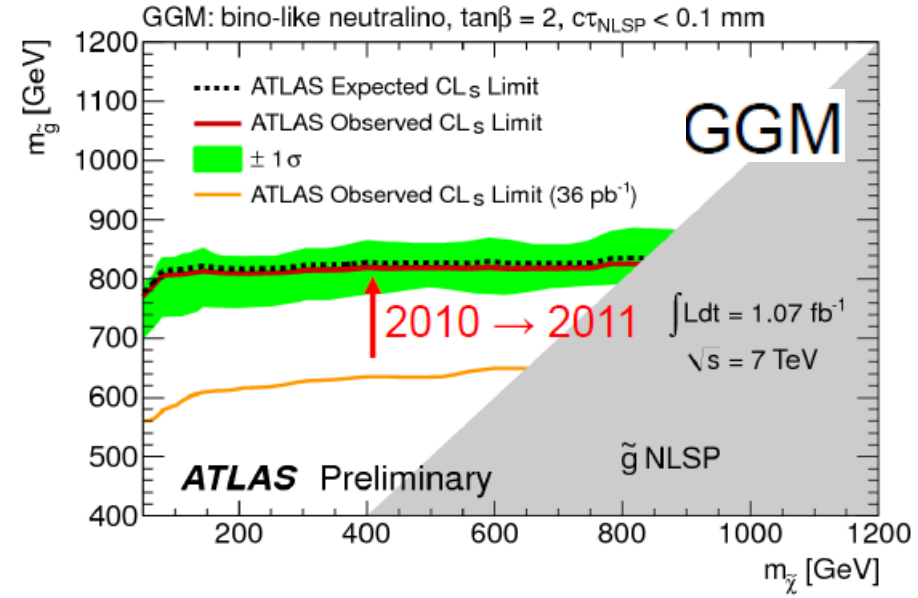
Preliminary results

Signal region:

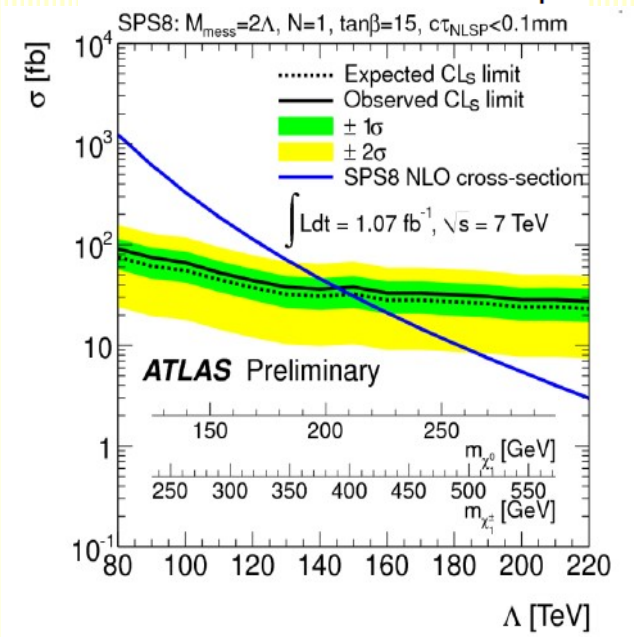
- ≥ 2 photons with E_T > 25 GeV
- E_T^{miss} > 125 GeV



Gluino for production
Bino-like neutralino as NLSP



minimal GMSB / SPS8 slope



Quickly, more summer results

b-jet with 1 lepton

ATLAS-CONF-2011-130

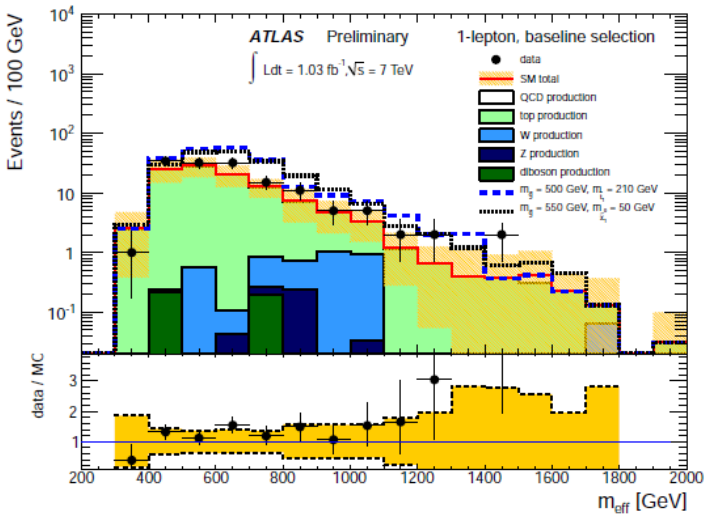
4 jets ($p_T > 50$ GeV), ≥ 1 b-jet ($p_T > 50$ GeV)

Exactly 1 lepton (e or μ)

$E_T^{Miss} > 80$ GeV

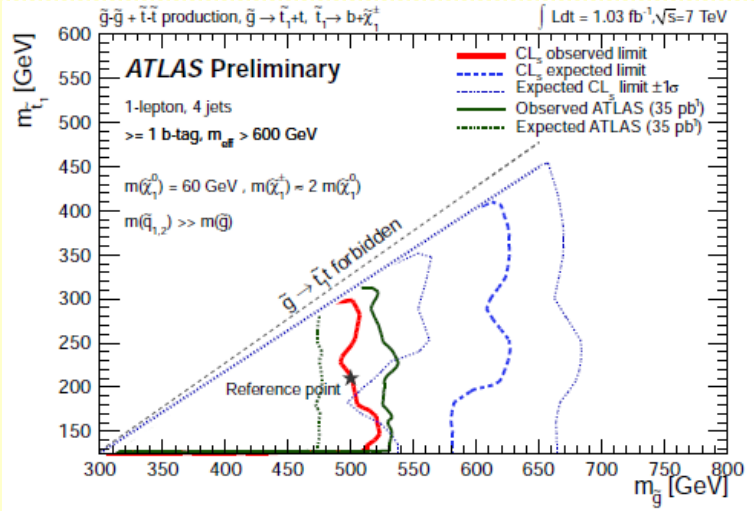
$$m_T = \sqrt{2p_T^{lep}E_T^{Miss} - 2\vec{p}_T^{lep}\vec{E}_T^{Miss}} > 100 \text{ GeV}$$

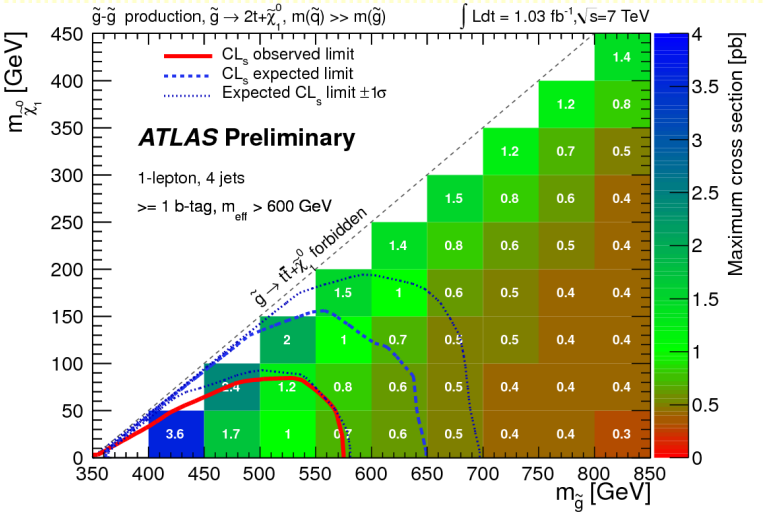
$$m_{Eff} = \sum_{i\leq 4}(p_T^{jet})_i + p_T^{lep} + E_T^{Miss} > 600 \text{ GeV}$$



Scenario 1: $\tilde{g}\tilde{g}$ and $\tilde{t}_1\tilde{t}_1$ production with $\tilde{g} \to \tilde{t}_1 t$ (BR=100%) and $\tilde{t}_1 \to b + \tilde{\chi}_1^{\pm}$ (BR=100%)

Scenario 2: $\tilde{g}\tilde{g}$ production with $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ (BR=100%) via off-shell stop decay.





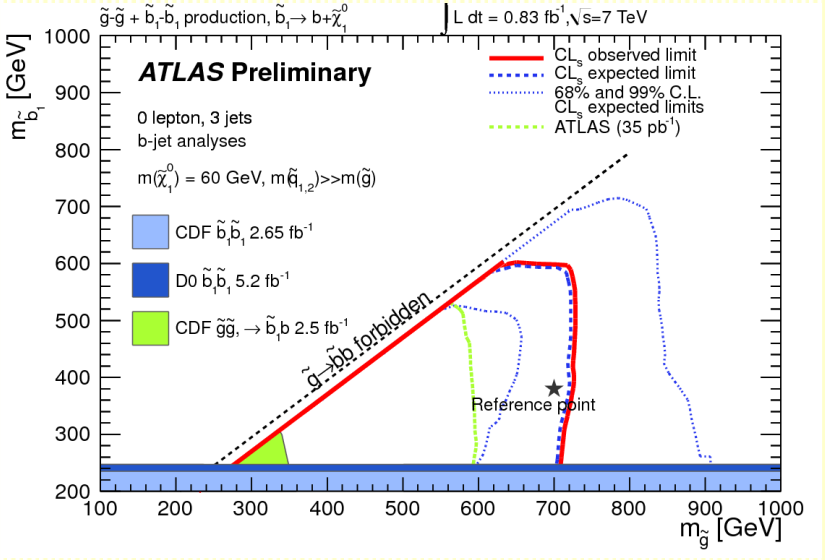
Quickly, more summer results

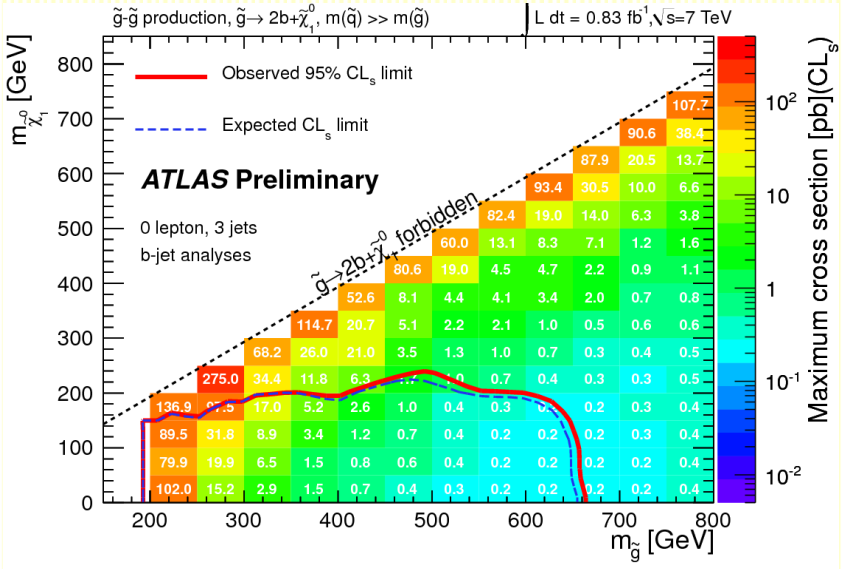
b-jet with no lepton

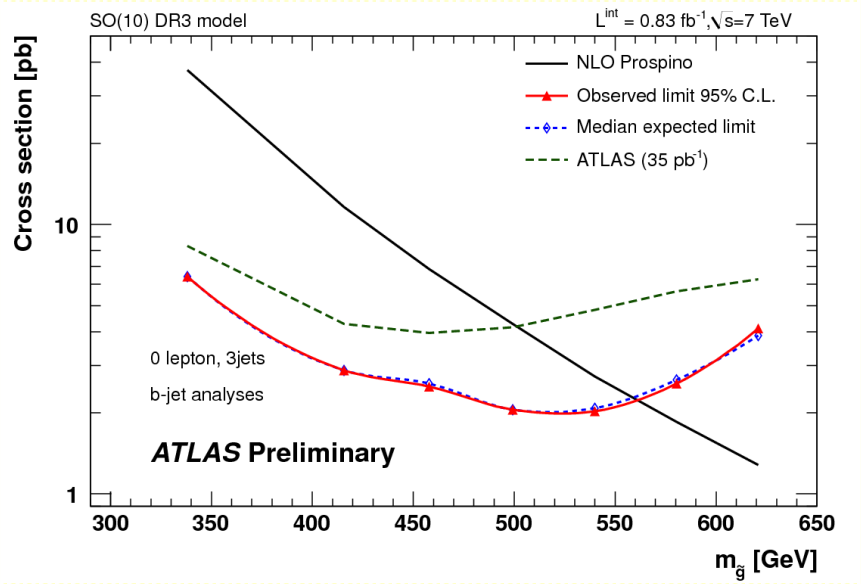
ATLAS-CONF-2011-098

lepton veto with p_T > 20 GeV (electron), 10 GeV (muon)

jet p_T>130,50,50 GeV	≥1 b-jet, m_{eff} > 500 GeV
E_T^{miss} > 130 GeV	≥1 b-jet, m_{eff} > 700 GeV
$\Delta\varphi_{min}$ > 0.4 rad	≥2 b-jet, m_{eff} > 500 GeV
E_T^{miss}/m_{eff} > 0.25	≥2 b-jet, m_{eff} > 700 GeV

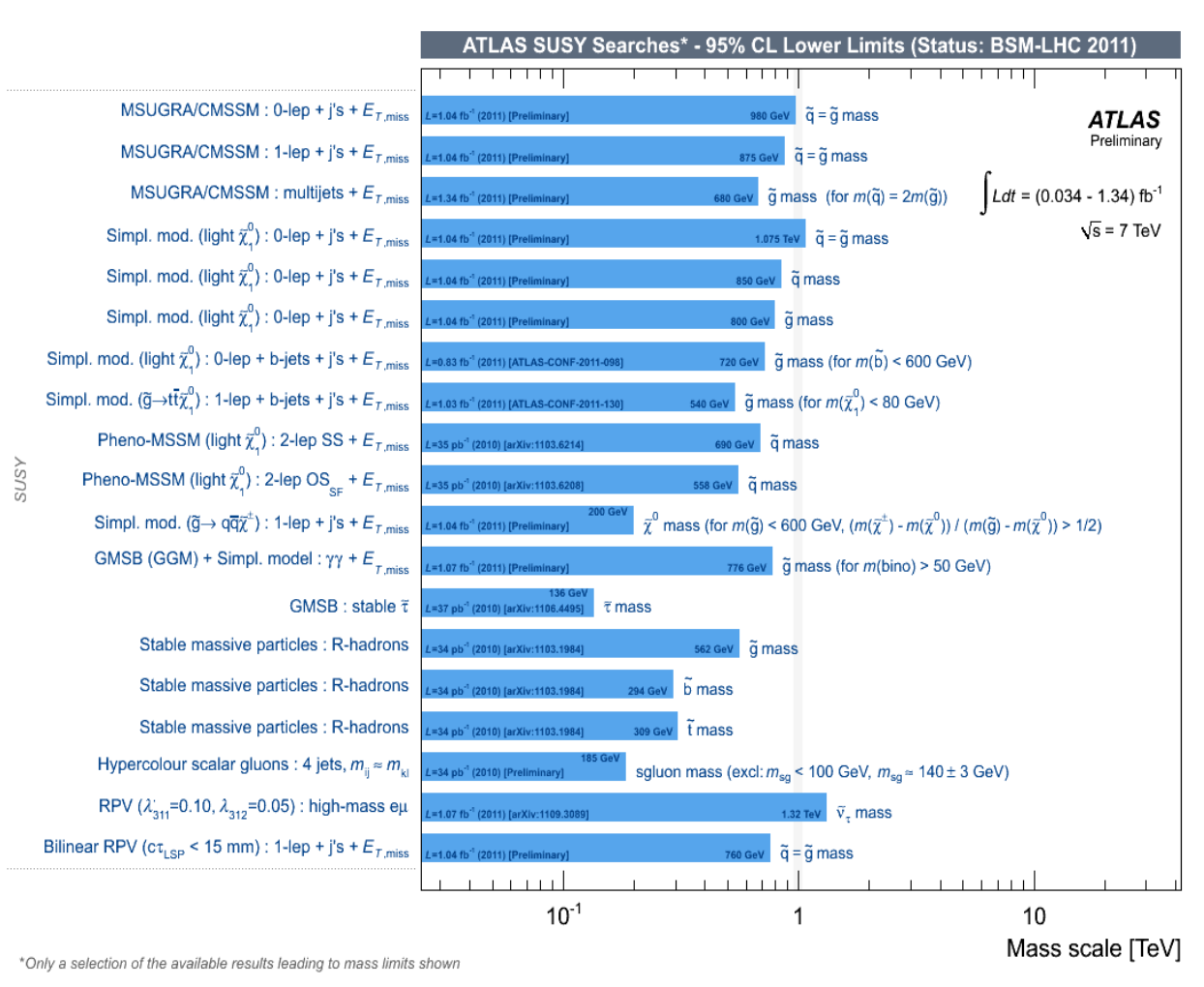






Summary and outlook

- More results than I could show today!



- Cover more topologies

Backup slides

Object identification

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

ϕ: azimuthal angle around the beam pipe

η= -ln tan(θ/2) where θ is the polar angle

- Jets (anti-Kt, R=0.4): p_T>20 GeV, |η|<2.5
  - Reject events compatible with noise or cosmics
  - Remove if ΔR(jet,electron)<0.2
- Electrons: p_T>20 GeV, |η|<2.47, Sum p_T of tracks (ΔR<0.2) < 0.1p_T
  - Remove if ΔR(jet,electron)<0.4
- Muons: p_T>20 GeV, |η|<2.4, Sum p_T of tracks (ΔR<0.2) < 1.8 GeV
  - Remove if ΔR(jet,muon)<0.4
- Missing transverse momentum (E_T^{miss}):
  - sum over the transverse momentum of all jets (up to |η|<4.9), electrons, muons and all calorimeter clusters not associated to such objects

Limit setting

Combined fit to the number of events in the SR and CRs,

$$L(n|s,b,\theta) = P_s \, x \, P_w \, x \, P_T \, x \, C_{syst},$$

n - observed events, s - signal counts to be tested, b - background counts,
θ- systematic uncertainties, treated as nuisance parameters with a Gaussian pdf.
P functions are Poisson probability distributions for event counts in SR, and in Top and W CRs.

Two fits performed:

- Discovery fit, signal events in SR left free, no signal contamination in CR (conservative approach as in this way BG can be only overestimated in SR),
- Exclusion fit, signal events fix to the expected values in SR and CRs,

Model independent upper limits:

- Derived from the discovery fit,
- Profile likelihood ratio technics,
- CL_s method.

From S. Pataraia

0-lepton control regions

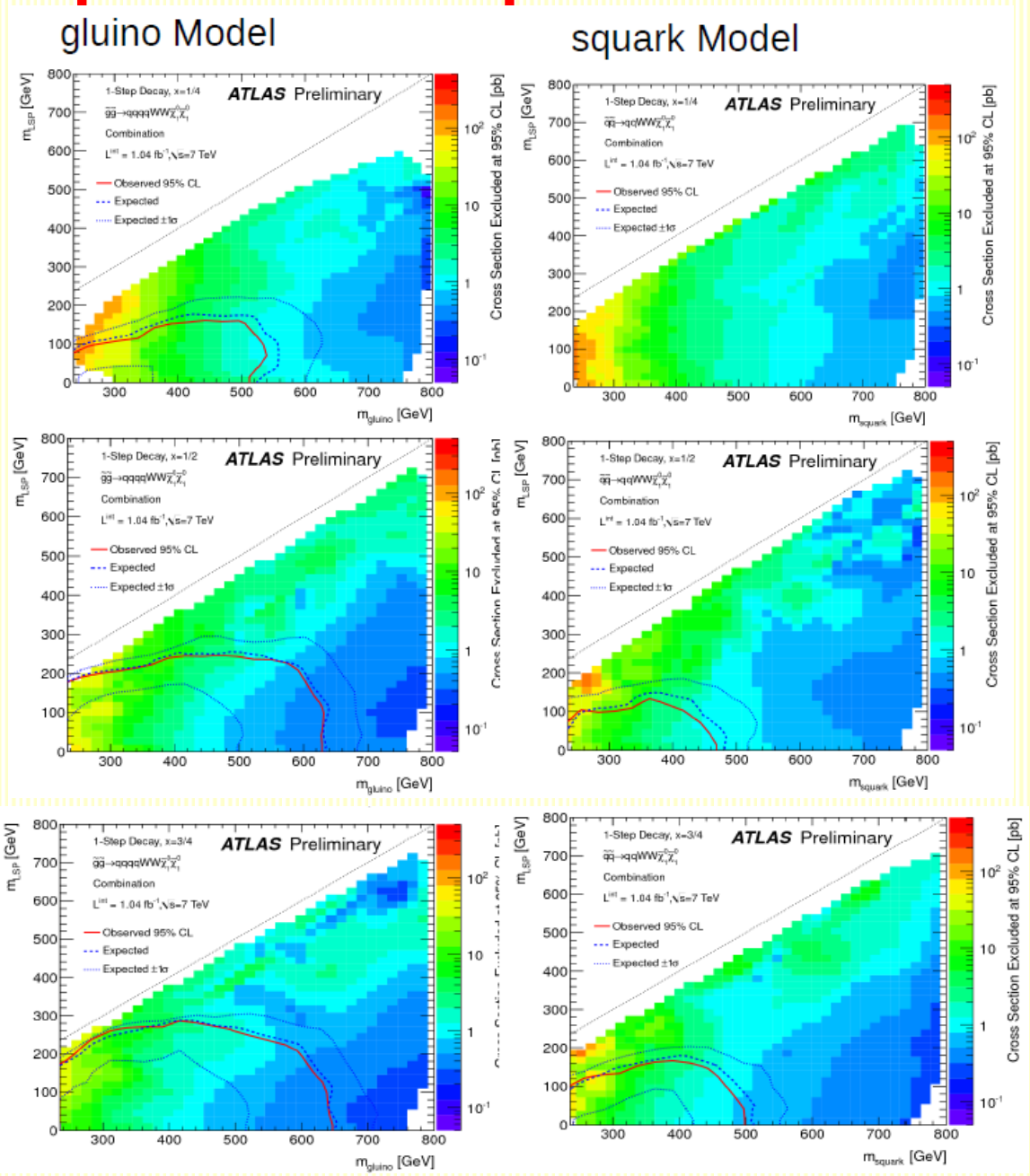
	Signal / Control Region					
	CR1a	CR1b	CR2	CR3	CR4	SR
Data	8	7	34	15	12	18
Targeted background	Z/γ+jets	Z/γ+jets	QCD multi-jet	W+jets	$t\bar{t}$ + single top	–
Transfer factor	0.374	0.812	0.063	0.196	0.372	–
Fitted Z/γ+jets	8.3	5.8	0.7	0.5	0.0	3.3
Fitted QCD multi-jet	–	–	29.8	0.8	0.6	2.1
Fitted W+jets	–	–	0.5	10.0	0.4	2.1
Fitted $t\bar{t}$ + single top	–	0.0	3.0	3.7	11.0	5.7
Fitted total background	8.3	5.9	34.0	15.0	12.0	13.1
Statistical uncertainty	±2.7	±1.2	±5.8	±3.9	±3.5	±1.9
Systematic uncertainty	±0.6	±1.7	±0.1	±0.1	±0.2	±2.5

1-lepton: simplified models

x = ¼

x = ½

x = ¾



1-lepton: systematics

Electron channel	3JL	3JT	4JL	4JT
Total statistical ($\sqrt{N_{\text{obs}}}$)	±8.4	±3.7	±6.4	±3.0
Total background systematic	±30.2	±7.4	±17.9	±3.7
Jet/$E_{\text{T}}^{\text{miss}}$ energy resolution	±5.9	±0.5	±4.2	±0.8
Jet/$E_{\text{T}}^{\text{miss}}$ energy scale	±18.6	±4.1	±13.6	±2.4
Lepton energy resolution	±0.5	±0.3	±0.1	±0.3
Lepton energy scale	±1.1	±0.3	±0.4	±0.5
b-tagging	±1.2	±0.2	±0.7	±0.1
MC stat. top	±5.8	±2.0	±3.8	±1.4
MC stat. W	±4.4	±2.3	±2.2	±1.3
Lepton misidentification rate	±1.4	±0.1	±0.2	< 0.1
Real lepton rate	±1.5	±0.3	±0.8	±0.1
Top background modeling	±15.9	±2.1	±9.8	±1.2
W background modeling	±19.0	±5.6	±5.1	±1.9
Pile-up	±5.1	±1.0	±2.5	±0.4

How to use the data

- For each signal region and analysis channel, the efficiency x acceptance is provided

  → validate your setup

  → interpret the data in your model