“Inclusive Searches for Squarks and Gluinos with the ATLAS Detector.”

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on behalf of the ATLAS Collaboration

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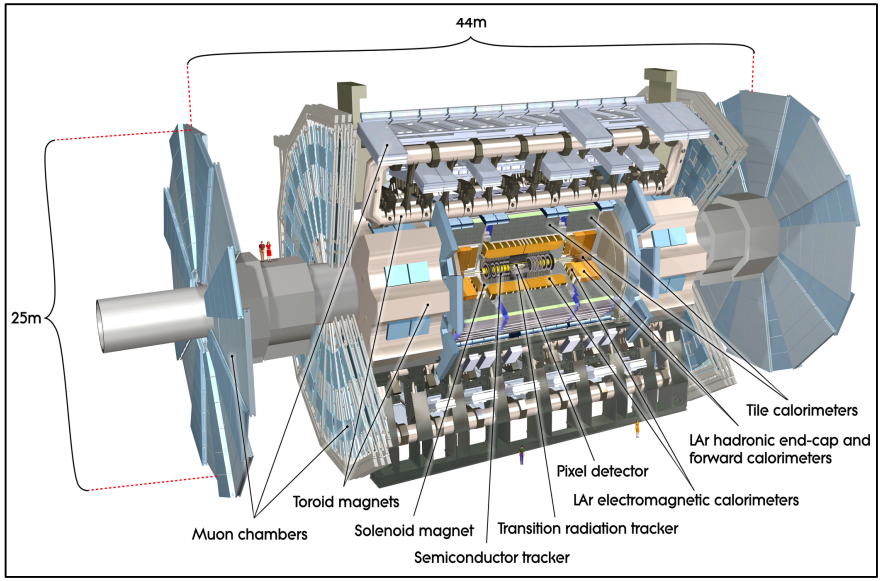
The ATLAS Experiment at the LHC

The ATLAS Detector:

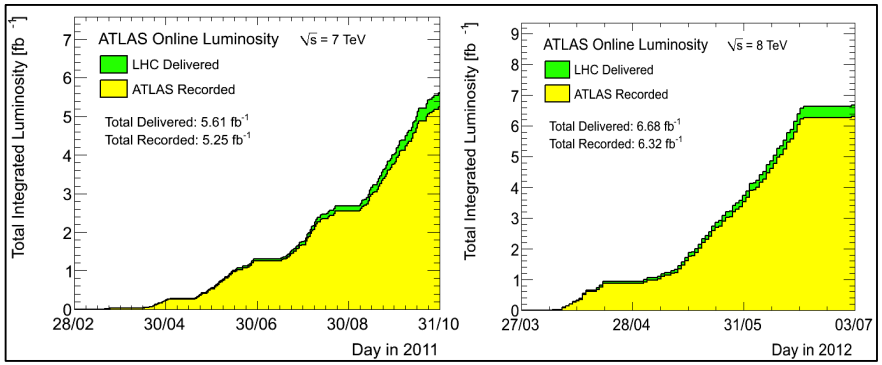
- **Inner detector** inside 2 T solenoid magnetic field within pseudorapidity $|\eta| < 2.5$.
- **Electromagnetic** and **hadronic calorimeters** extending to $|\eta| < 4.9$.
- **Muon spectrometer** inside toroidal magnetic system covering $|\eta| < 2.7$.



Data collected in proton-proton collisions:

- 45 pb^{-1} at $\sqrt{s}$ = 7 TeV in 2010
- 5.3 fb^{-1} at $\sqrt{s}$ = 7 TeV in 2011
- 6.3 fb^{-1} at $\sqrt{s}$ = 8 TeV in 2012 (to date)

→ Results shown in this presentation based on full 2011 dataset, corresponding to 4.7 fb^{-1} after data-quality requirements.



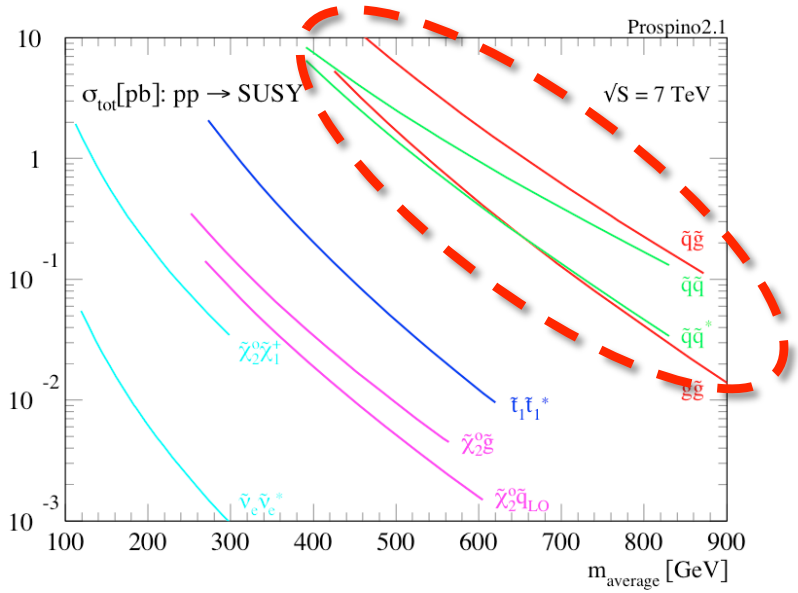
Inclusive SUSY searches with ATLAS

If squarks and gluinos exist at LHC accessible energies and R-parity is conserved:

- Pair-production.
- Direct or cascade decays to the stable lightest SUSY particle (LSP).

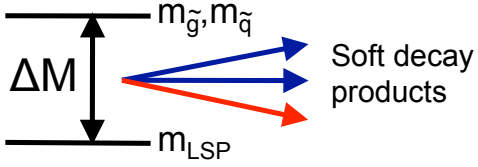
Experimental signature for inclusive searches:

- Missing transverse energy ($E_{T,miss}$).
- Jets.
- Other objects, e.g. leptons.



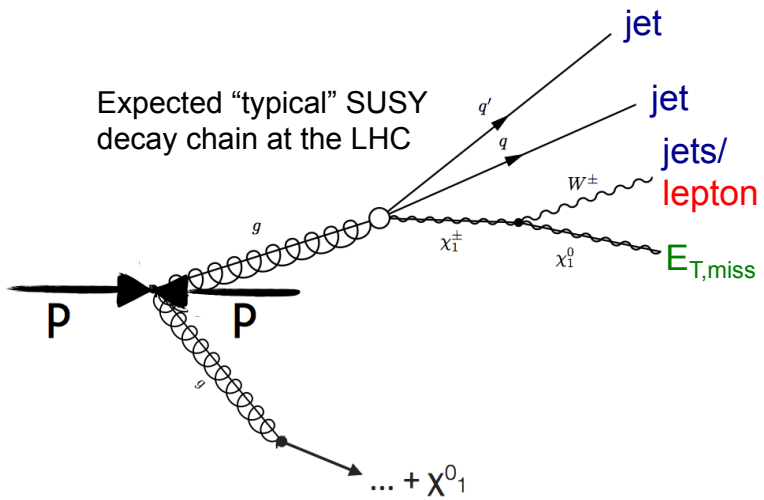
Scope of inclusive searches in ATLAS extended to SUSY models with compressed spectra:

- Small $\Delta M_{g,q\text{-}LSP}$.
- Soft decay products.
- → Profit from presence of initial state radiation.



Analyses in this presentation:

- 0-lepton, ≥ 2-6 jets, $E_{T,miss}$ [ATLAS-CONF-2012-033]
- 0-lepton, ≥ 6-9 jets, $E_{T,miss}$ [arXiv:1206.1760]
- 1-lepton, ≥ 2-4 jets, $E_{T,miss}$ [ATLAS-CONF-2012-041]



0-lepton + 2-6 jets + $E_{T,miss}$ Analysis: Overview

ATLAS-CONF-2012-033

- Events selected with jet + $E_{T,miss}$ triggers.
- Events with electrons / muons vetoed.
- 6 inclusive channels with increasing jet multiplicity to obtain best reach over m_{squark}-m_{gluino} plane.

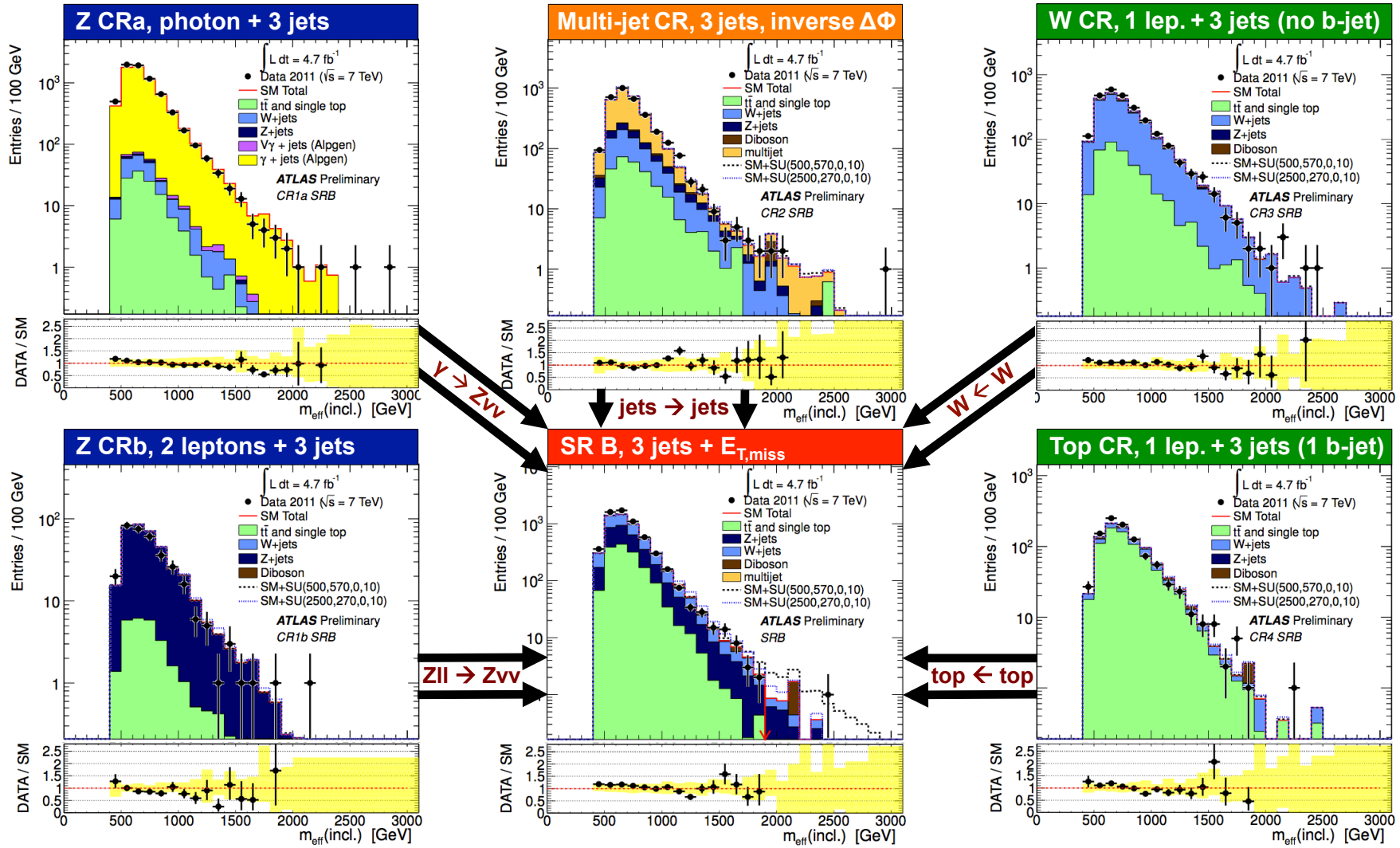
Requirement	Channel					
	A	A'	B	C	D	E
E_T^{miss} [GeV] >			160			
$p_T(j_1)$ [GeV] >			130			
$p_T(j_2)$ [GeV] >			60			
$p_T(j_3)$ [GeV] >	–	–	60	60	60	60
$p_T(j_4)$ [GeV] >	–	–	–	60	60	60
$p_T(j_5)$ [GeV] >	–	–	–	–	40	40
$p_T(j_6)$ [GeV] >	–	–	–	–	–	40
$\Delta\phi$(jet, E_T^{miss})$_{min}$ >	0.4 (i = {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

- $M_{eff}^{(inc)}$: scalar sum of $E_{T,miss}$, p_T of (all) jets with p_T > 40 GeV
- $\Delta\Phi$ (jet, $E_{T,miss}$): minimum azimuthal angle between jets and $E_{T,miss}$

- Signal region (SR) A' optimized for sensitivity to compressed SUSY spectra.
- Reduction of multi-jet background via cuts $\Delta\Phi$(jets, $E_{T,miss}$) and the ratio $E_{T,miss}$ / M_{eff}.
- Each channel has up to 3 SRs with loose / medium / tight M_{eff} cuts → in total 11 inclusive SRs.
- Background estimation:
  - Isolate dominant backgrounds in control regions (CR)
  - Derive transfer factors (TF) to relate number of events in CR and SRs.

0-lepton + 2-6 jets + $E_{T,miss}$ Analysis: Backgrounds

- 5 CRs for each SR. Extrapolation to the SRs with TFs (data-driven and from simulation).



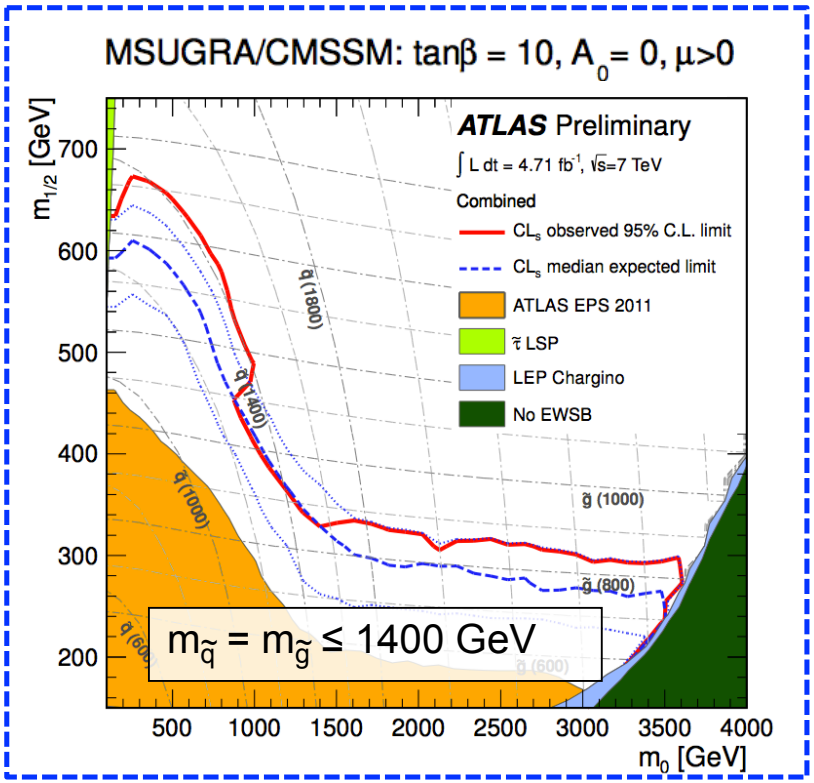
0-lepton + 2-6 jets + $E_{T,miss}$ Analysis: Results

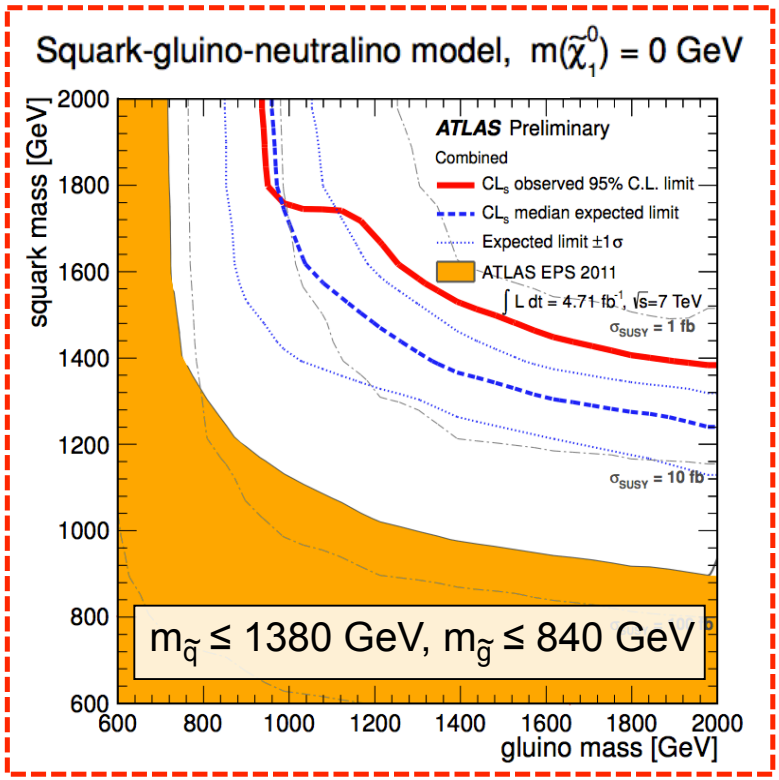
- No significant excess observed in any of the signal regions. Limits derived using for each model point the SR with the best expected sensitivity.

See backup for result tables

→ MSUGRA/CMSSM models with tanβ = 10, A_0 = 0 and μ > 0.

→ Simplified squark-gluino-neutralino model (m_{LSP} = 0).



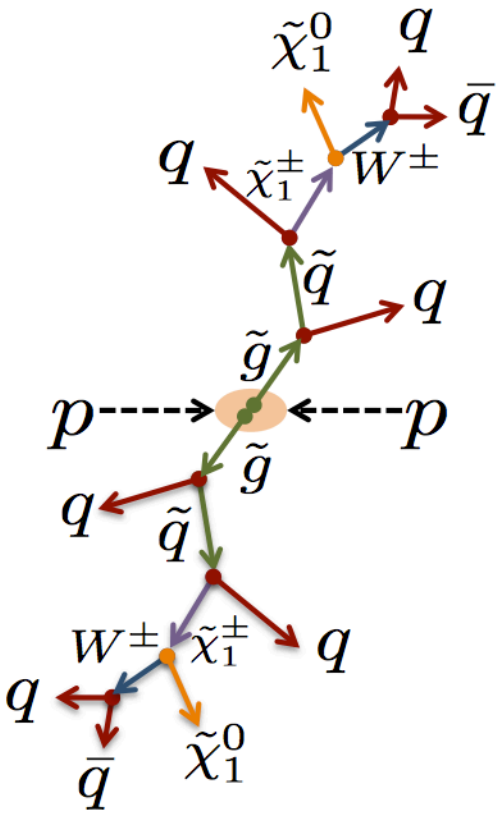


0-lepton + 6-9 jets + $E_{T,miss}$ Analysis: Overview

arXiv:1206.1760

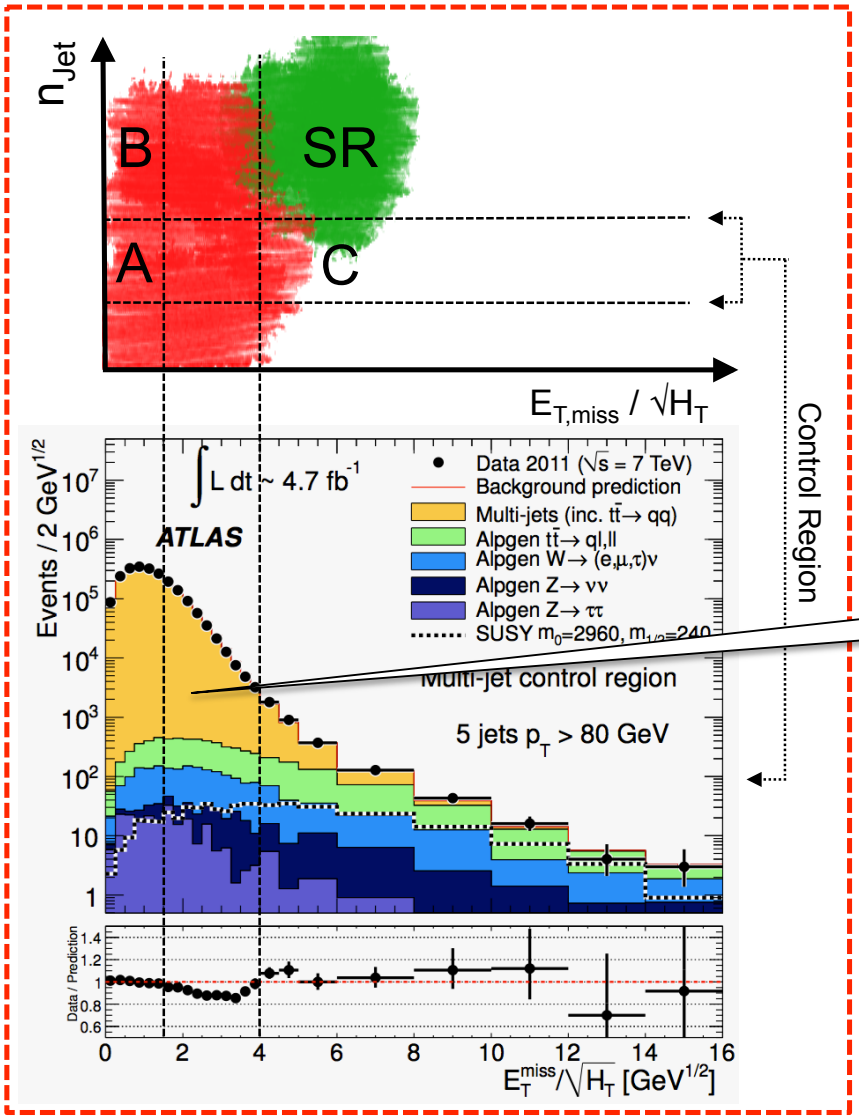
- Analysis targeting models with longer decay chains:
  - Many jets (≥6-9)
  - Softer $E_{T,miss}$

Signal region	7j55	8j55	9j55	6j80	7j80	8j80
Number of isolated leptons (e, μ)	$= 0$					
Jet p_T	> 55 GeV			> 80 GeV		
Jet $\|\eta\|$	< 2.8					
Number of jets	≥ 7	≥ 8	≥ 9	≥ 6	≥ 7	≥ 8
$E_T^{miss}/\sqrt{H_T}$	> 4 GeV$^{1/2}$					



- Events selected with multi-jet triggers.
- Events with electron / muons vetoed as in 0-lepton, 2-6 jets analysis.
- Final selection variable is $E_{T,miss}$ / $\sqrt{H_T}$, where H_T is the scalar sum of jets with $p_T > 40$ GeV.

0-lepton + 6-9 jets + $E_{T,miss}$ Analysis: Backgrounds



Template extracted from 4 jets selection.

Multi-jet background (including fully hadronic tt):

- Dominant due to absence of ΔΦ (jet,$E_{T,miss}$) cut and lower $E_{T,miss}$ requirements.
- Obtain $E_{T,miss}$ / $\sqrt{H_T}$ shape templates at lower jet multiplicities.
- Normalize shape in SR at low $E_{T,miss}$ / $\sqrt{H_T}$ using events in regions $N_{SR} = N_C * N_B / N_A$ after subtraction of leptonic backgrounds.

→ Assumption: $E_{T,miss}$ / $\sqrt{H_T}$ independent of jet multiplicity.

'Leptonic' backgrounds (semi- and fully-leptonic tt, W/Z + jets):

- $t\bar{t}$ / W+jets CRs: 1 muon, ≥ 1 / 0 b-jets. Treat muon as jet and apply SR selections.
- Z+Jets CR: 2 muons, $m_{\mu\mu}$ in Z-mass window. Add Z p_T to $E_{T,miss}$ and apply SR selections.
- TFs from simulation to extrapolate to SRs.

0-lepton + 6-9 jets + $E_{T,miss}$ Analysis: Results

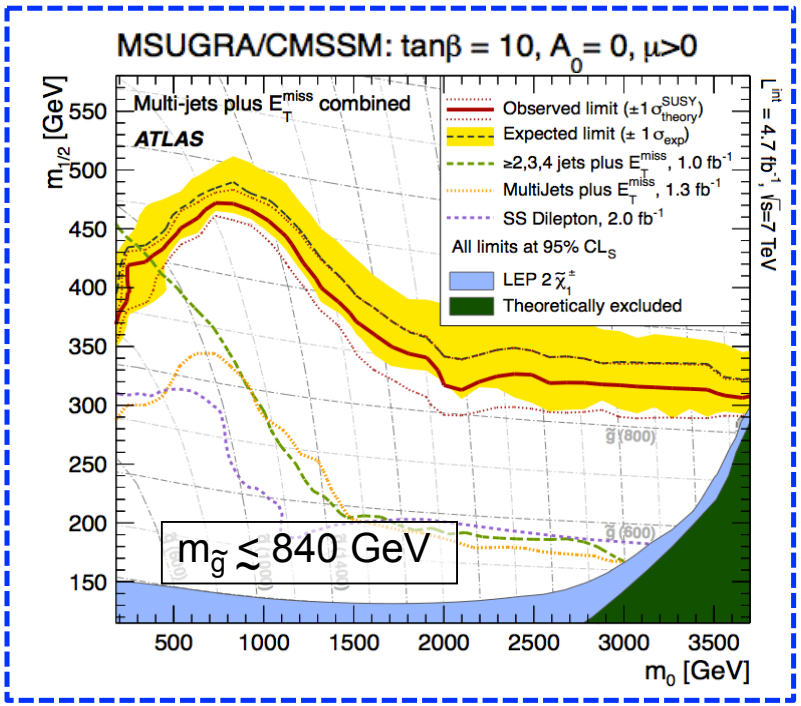
- No significant excess observed in any of the signal regions. Limits derived using for each model point the SR with the best expected sensitivity.

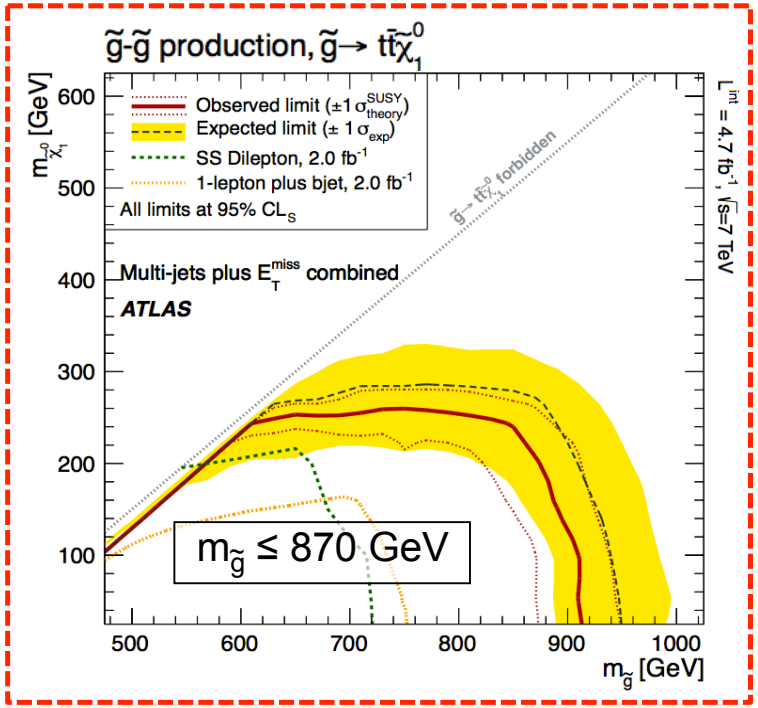
Signal region	7j55	8j55	9j55	6j80	7j80	8j80
Total Standard Model	167±34	17±7	1.9±0.8	107±21	8.6±2.5	0.80±0.45
Data	154	22	3	106	15	1

Full table in backup

→ MSUGRA/CMSSM models with tanβ = 10, A_0 = 0 and μ > 0.

→ Simplified Model: Gluino pair production and decay via virtual stops to tt and neutralino.





1-lepton + 2-4 jets + $E_{T,miss}$ Analysis: Overview

ATLAS-CONF-2012-041

	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	—

- All signal regions mutually exclusive to facilitate combination.
- m_T: transverse mass calculated from lepton and $E_{T,miss}$.
- m_{eff}^{inc}: sum over $E_{T,miss}$, p_T of the lepton and all jets in the event.

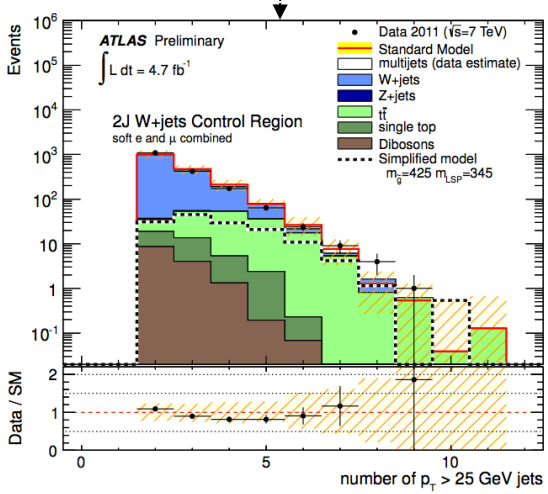
- **2 "hard"- lepton SRs:**
  - Optimized for CMSSM/MSUGRA and models with large mass spectra.
  - Higher p_T thresholds for all objects, higher jet multiplicities, tight cuts on $E_{T,miss}$.
  - Final discriminating variable m_{eff}^{inc}.
- **1 "soft"- lepton SR (new!):**
  - Optimized for models with compressed mass spectra.
  - Low-p_T thresholds for electrons (muons) and subleading jet, high-p_T leading jet (initial state radiation), tight cuts on $E_{T,miss}$.
  - Final discriminating variable $E_{T,miss}$ / m_{eff}.

(NB: Cuts on final discriminating variables lowered / removed for exclusion to allow shape fit in SRs.)

1-lepton + 2-4 jets + $E_{T,miss}$ Analysis: Backgrounds

	3- and 4-jet W control	3- and 4-jet $t\bar{t}$ control	soft-lepton W control	soft-lepton $t\bar{t}$ control
N_{jet}	≥ 3	≥ 3	Same as signal region	
p_T^{jet} (GeV)	> 80, 25, 25	> 80, 25, 25	Same as signal region	
N_{jet} (b-tagged)	0	≥ 1	0	≥ 1
E_T^{miss} (GeV)	[30,120]	[30,120]	[180,250]	[180,250]
m_T (GeV)	[40,80]	[40,80]	[40,80]	[40,80]
m_{eff}^{inc} (GeV)	> 400	> 400	—	—

e.g.



- Dominant backgrounds: $t\bar{t}$, W+jets processes enriched in dedicated CRs.
- Minor backgrounds: Multi-jets (data-driven method), Z+jets, single-top, di-boson production (simulation).
- Backgrounds in the SRs are determined with a simultaneous fit based on the profile likelihood method.

→ Shape of the jet multiplicity distribution is used in the W+jets and tt CRs.

→ Extrapolation from CRs to SRs via TFs taken from simulation.

→ Fit overcontrained: Some uncertainties are reduced in the fit using data.

- The validity of the background estimates is tested in validation regions between the CRs and SRs.

1-lepton + 2-4 jets + $E_{T,miss}$ Analysis: Results

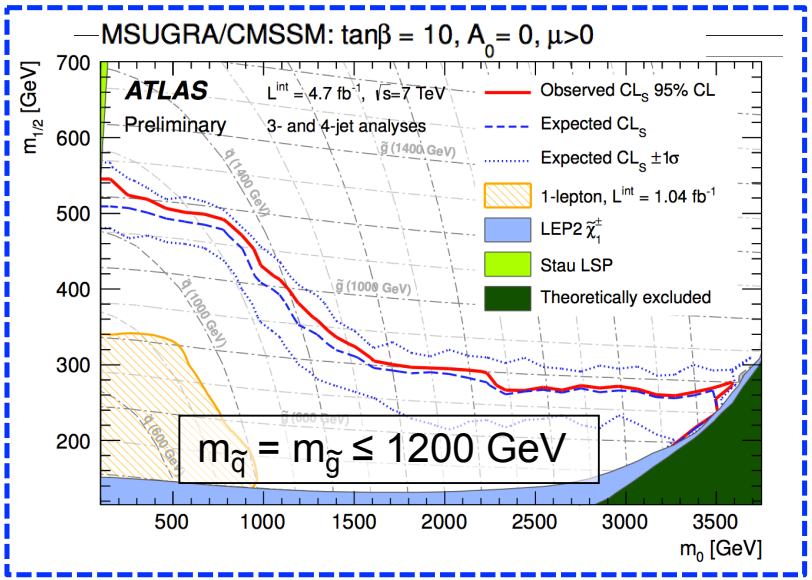
- No significant excess observed in any SR.

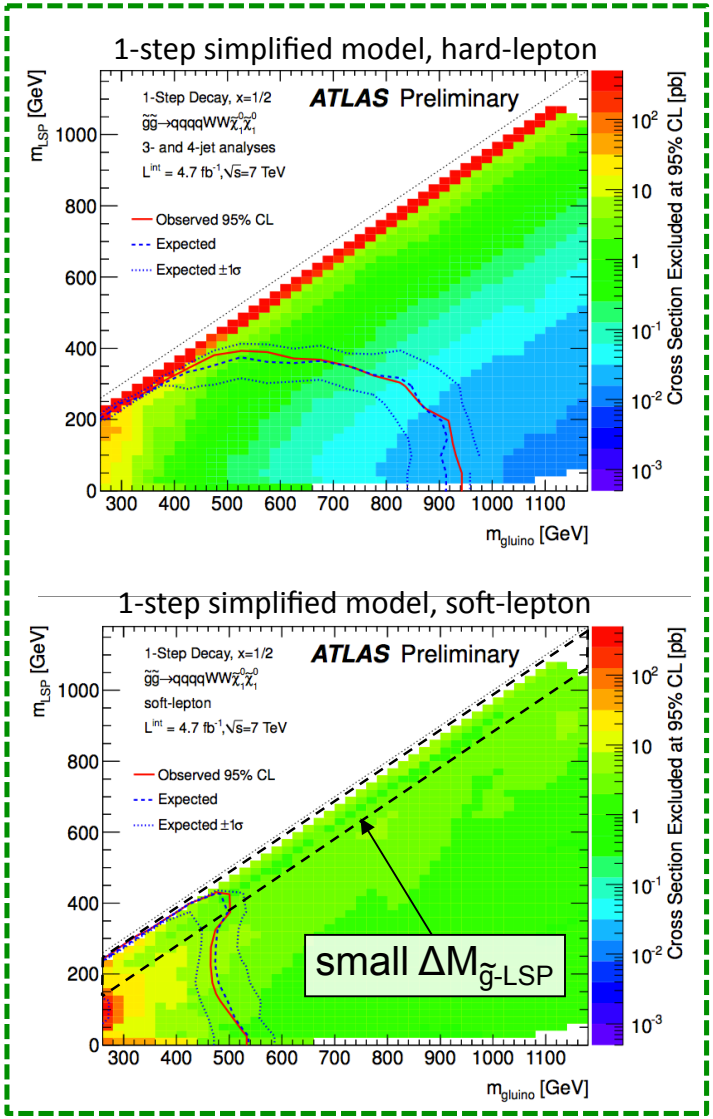
	3-jet	4-jet	soft lepton
Observed events	3	6	26
Fitted bkg events	5.7 ± 4.0	8.3 ± 3.1	32 ± 11

- Limits derived from shape-fit in SRs and combination of results.

→ MSUGRA/CMSSM models with tanβ = 10, A_0 = 0 and μ > 0.

→ 1-step simplified model with gluino pair-production followed by the decay $\tilde{g} \rightarrow q\bar{q}'\tilde{X}_1^{\pm} \rightarrow q\bar{q}'W^{\pm}\tilde{X}_1^0$, with $m_{\tilde{X}_1^{\pm}} = (m_{\tilde{g}} + m_{\tilde{X}_1^0})/2$.





Summary and Outlook

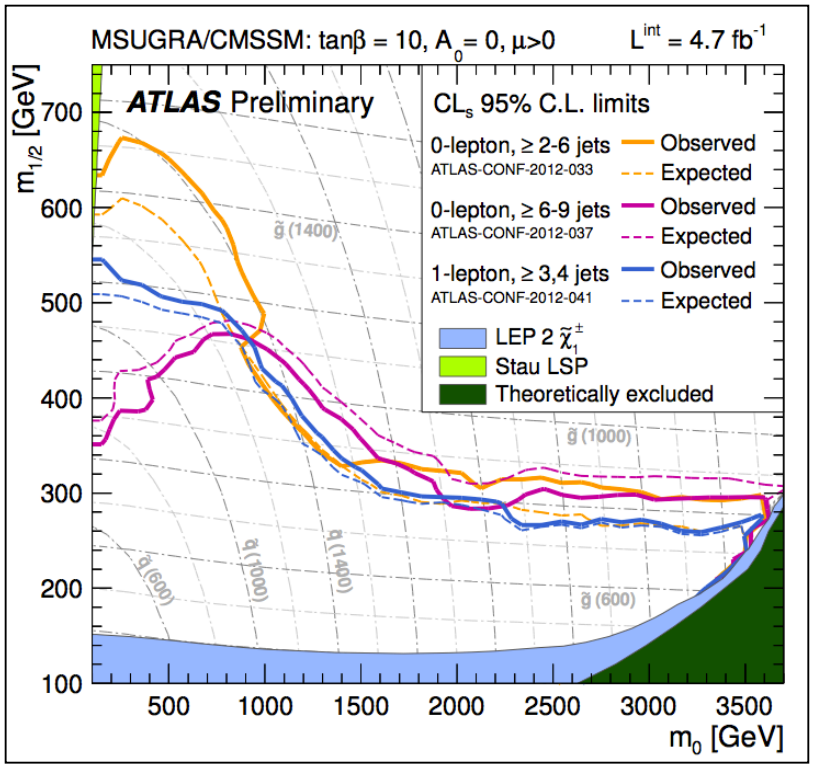
Summary:

- Three inclusive searches for squarks and gluinos have been presented using the full 2011 ATLAS dataset of 4.7 fb^{-1}.
- Major improvements:
  - Increased sensitivity to SUSY models with compressed mass spectra.
  - Increased sensitivity to multi-jet scenarios.
  - Reduction of systematic uncertainties.
- No significant excess found in any of the analyses.
- Previous exclusion limits significantly improved.

Outlook:

- Updates using the full 2011 data set are currently being finalized with additional interpretations and additional final states.
- First 8 TeV results expected soon.

→ Stay tuned ☺

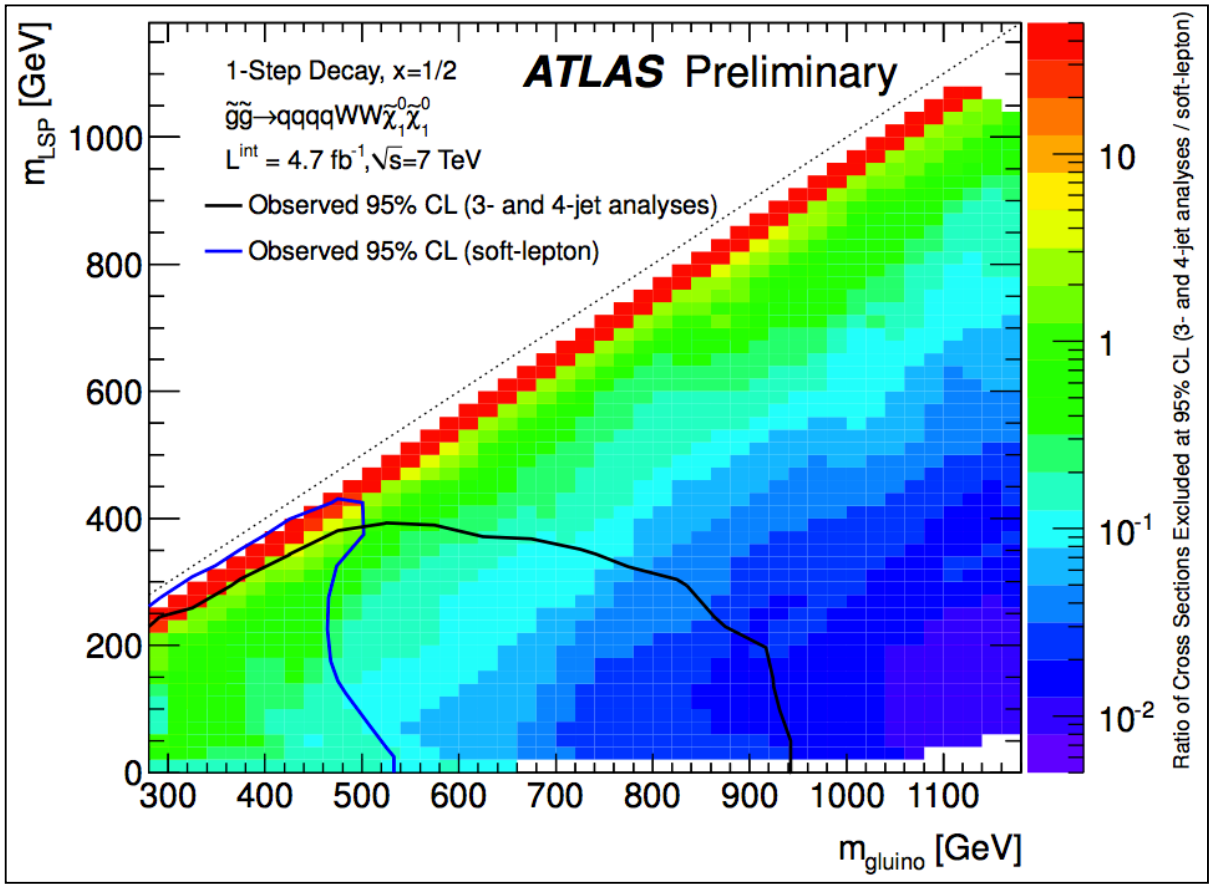


GMSB / AMSB interpretations:
- Steffen SCHAEPE, 5th July, 11:45
- Andrew HAAS, 6th July, 11:30

Backup

Comparison of Soft and Hard 1-Lepton Limits

The ratio of excluded cross sections of the soft and hard 1-lepton analyses demonstrates the improvement of the upper limits in the near diagonal region where small mass splitting between the SUSY particles are expected.



0-lepton, 2-6 jets Analysis: Signal Region Tables

Process	Signal Region					
	SRC loose	SRE loose	SRA medium	SRA' medium	SRC medium	SRE medium
$t\bar{t}$+ Single Top	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)
Multi-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 p-value (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
$t\bar{t}$+ Single Top	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)
Multi-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 p-value (Gaus. σ)	0.98(-2.1)	0.95(-1.7)	0.018(2.1)	0.29(0.55)	0.45(0.13)

0-lepton, 6-9 jets Analysis: Signal Region Tables

Signal region	**7j55**	**8j55**	**9j55**	**6j80**	**7j80**	**8j80**
Multi-jets	91±20	10±3	1.2±0.4	67±12	5.4±1.7	0.42±0.16
$t\bar{t} \rightarrow q\ell, \ell\ell$	55±18	5.7±6.0	0.70±0.72	24±13	2.8±1.8	0.38±0.40
W + jets	18±11	0.81±0.72	0+0.13	13±10	0.34±0.21	0+0.06
Z + jets	2.7±1.6	0.05±0.19	0+0.12	2.7±2.9	0.10±0.17	0+0.13
Total Standard Model	**167±34**	**17±7**	**1.9±0.8**	**107±21**	**8.6±2.5**	**0.80±0.45**
Data	**154**	**22**	**3**	**106**	**15**	**1**
$N^{95\%}_{\mathrm{BSM,max}}$ (exp)	72	16	4.5	46	8.4	3.5
$N^{95\%}_{\mathrm{BSM,max}}$ (obs)	64	20	5.7	46	15	3.8
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (exp) [fb]	15	3.4	0.96	9.8	1.8	0.74
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (obs) [fb]	14	4.2	1.2	9.8	3.2	0.81
p_{SM}	0.64	0.27	0.28	0.52	0.07	0.43

1-lepton, 2-4 jets Analysis: Signal Region Tables

	3-jet	4-jet	soft lepton
Observed events	3	6	26
Fitted bkg events	5.7 ± 4.0	8.3 ± 3.1	32 ± 11
Fitted top events	2.0 ± 1.5	5.3 ± 2.1	8.6 ± 3.4
Fitted W/Z+jets events	2.9 ± 2.1	2.0 ± 0.7	15 ± 7
Fitted other bkg events	0.5 ± 0.7	0.9 ± 0.8	0.62 ± 0.24
Fitted multijet events	0.3 ± 0.4	0.17 ± 0.30	8 ± 4
MC exp. SM events	5.6	7.9	32
MC exp. top events	1.9	5.0	8.6
MC exp. W/Z+jets events	3.1	2.0	15
MC exp. other bkg events	0.3	0.7	0.62
Data-driven multijet events	0.3	0.17	8

0-lepton + 2-6 jets + $E_{T,miss}$ Analysis: Backgrounds

- 5 categories of control regions. Kinematic selections of CRs close to the 11 SRs → 55 CRs.

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

- Z(→ νν) + jets background (CR1a/b):
  - Add photon p_T (Z p_T) to $E_{T,miss}$ in CR1a(b) to mimic $E_{T,miss}$ in Z(→ νν) + jets events.
  - Exploit similar event kinematics of Z(→ νν) + jets and γ + jets at high vector boson p_T to derive TFs based on the cross-section ratio of the two processes (CR1a).
  - Derive TFs from MC in CR1b.
- Multi-jet background (CR2):
  - TFs are estimated using a data-driven technique based on the smearing of well-measured low $E_{T,miss}$ events by the detector resolution.
- W (→ lν) + jets and top background (CR3, CR4):
  - Add leptons as jets in CR3 and CR4 to mimic W (→ lν) + jets and top events in SRs.
  - Derive TFs from MC.

→ TFs and CRs event yields input to global likelihood fit performed separately for each SR.