ATLAS jets+MET searches: Search for Supersymmetry with jets and missing transverse energy at ATLAS

Duong Nguyen
on behalf of the ATLAS collaboration

BNL SUSY Workshop
Brookhaven National Lab
May 2, 2012

Introduction

- Search for squarks and gluinos in the final state with jets and missing transverse energy with isolated electron or muon veto.
- 4.7 fb^{-1} of 7 TeV collision data in 2011 run is used
- 2-6 jets search:

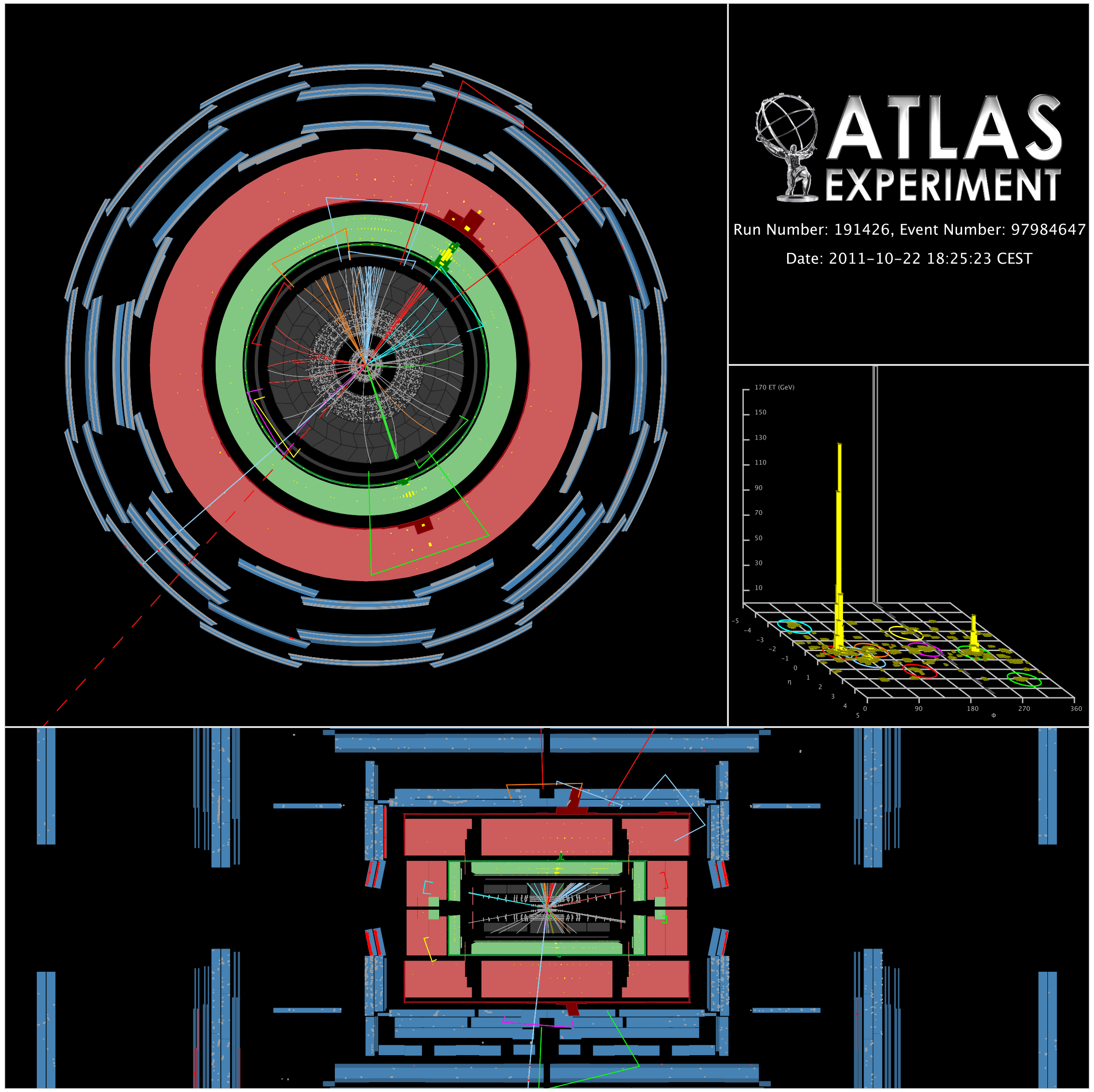
$$\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$$

$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$$

$$\tilde{q} \rightarrow q\tilde{\chi}_1^0$$

- Extend to 6-9 jets search to be sensitive to non-leptonic many-body decays and long decay chains

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



- 4 leading jets with pT = 974, 276, 146 and 61 GeV
- Large missing transverse energy: 984 GeV

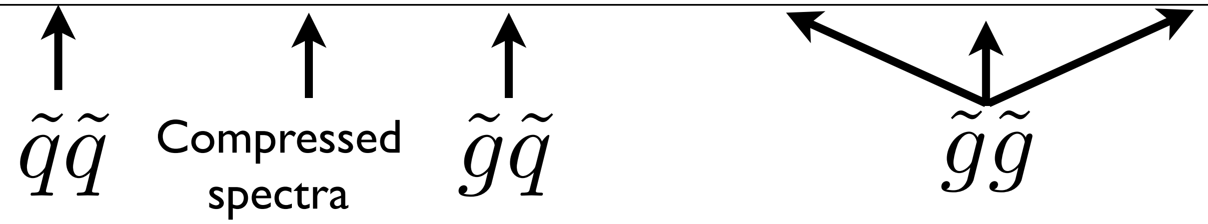
2-6 jets search

Signal Regions

QCD rejection →

Signal region selection {

Requirement	Channel					
	A	A’	B	C	D	E
$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV] >	160					
$p_{\mathrm{T}}(j_1)$ [GeV] >	130					
$p_{\mathrm{T}}(j_2)$ [GeV] >	60					
$p_{\mathrm{T}}(j_3)$ [GeV] >	–	–	60	60	60	60
$p_{\mathrm{T}}(j_4)$ [GeV] >	–	–	–	60	60	60
$p_{\mathrm{T}}(j_5)$ [GeV] >	–	–	–	–	40	40
$p_{\mathrm{T}}(j_6)$ [GeV] >	–	–	–	–	–	40
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4 ($i = \{1, 2, (3)\}$)			0.4 ($i = \{1, 2, 3\}$), 0.2 (p_{T} > 40 GeV jets)		
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(Nj)$ >	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



$\tilde{q}\tilde{q}$

Compressed spectra

$\tilde{g}\tilde{q}$

$\tilde{g}\tilde{g}$

$$m_{eff} = E_T^{miss} + \sum_{SRjets} p_T$$

$$m_{eff}(incl.) = E_T^{miss} + \sum_{jets p_T > 40GeV} p_T$$

- Jet+MET triggers
- 6 channels, 11 signal regions for different topologies and mass ranges

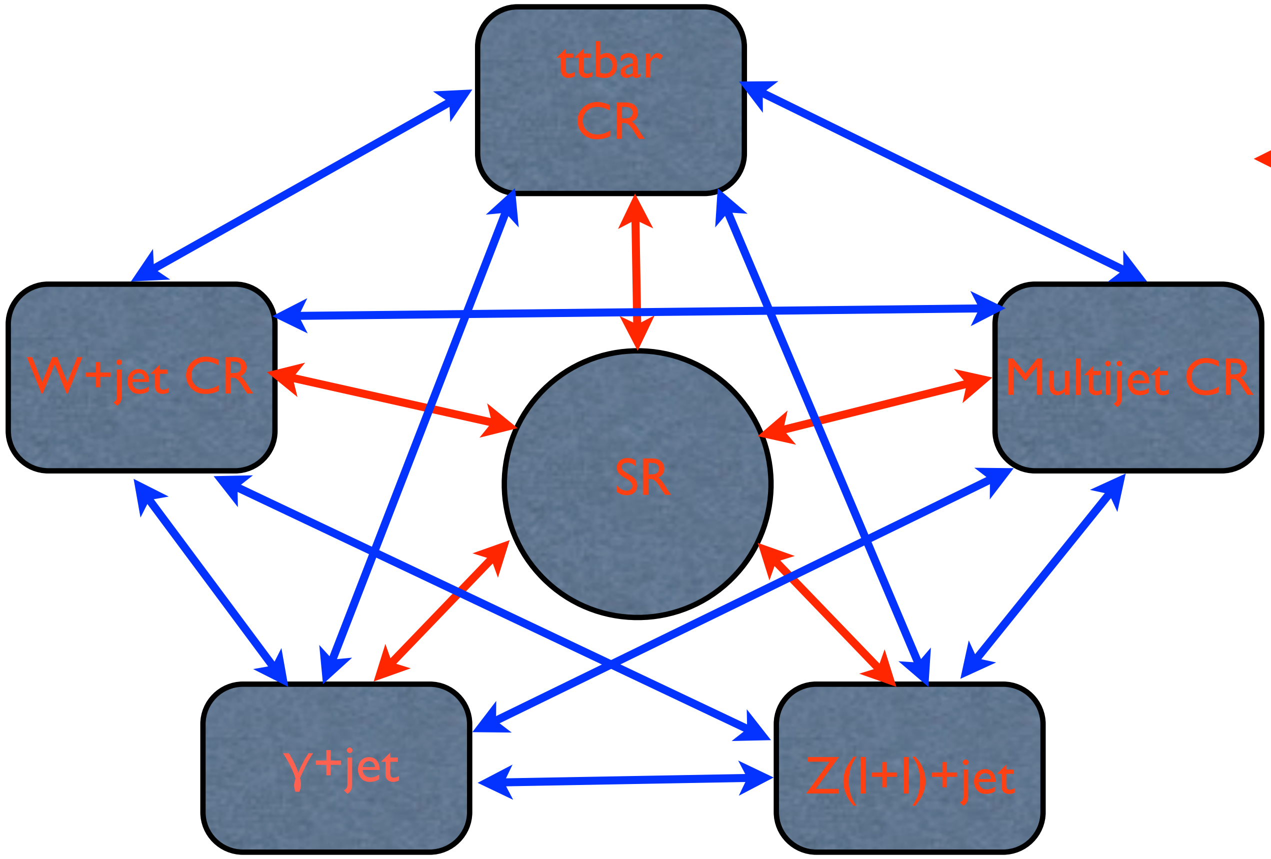
Backgrounds and Control Regions

- Main backgrounds are: multijet, Z+jet, W+jet, ttbar+singlge top
- For each SRs, we define 5 CRs for each background (Z+jet has two CRs corresponding to Z leptonic and gamma+jet selections)
- Define transfer factors for each background process:
  - Control region-signal region transfer factors to estimate contribution to SR

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

  - Control region-control region transfer factors to take into account the background correlations between control regions

Profile Likelihood Ratio fit with transfer factors and number of observed events in CRs as inputs to constrain background estimation in SRs

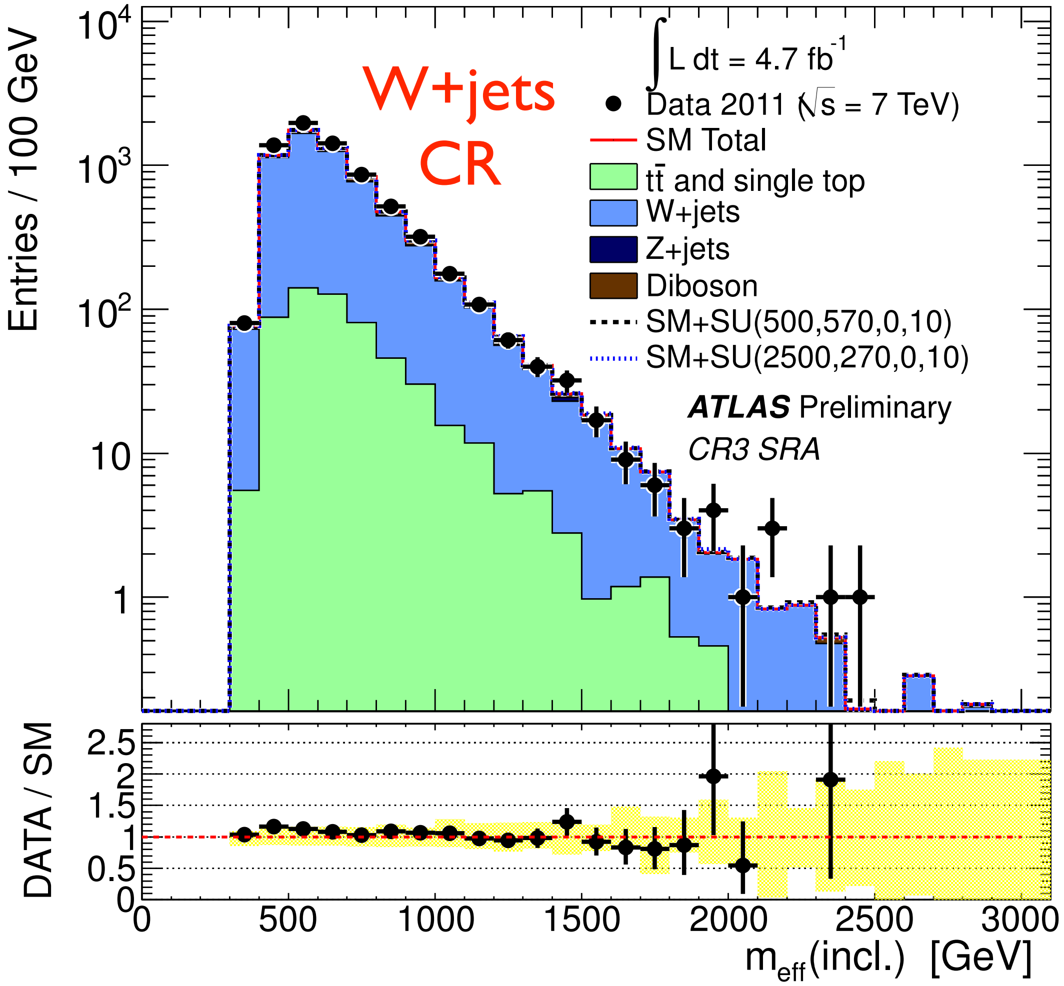


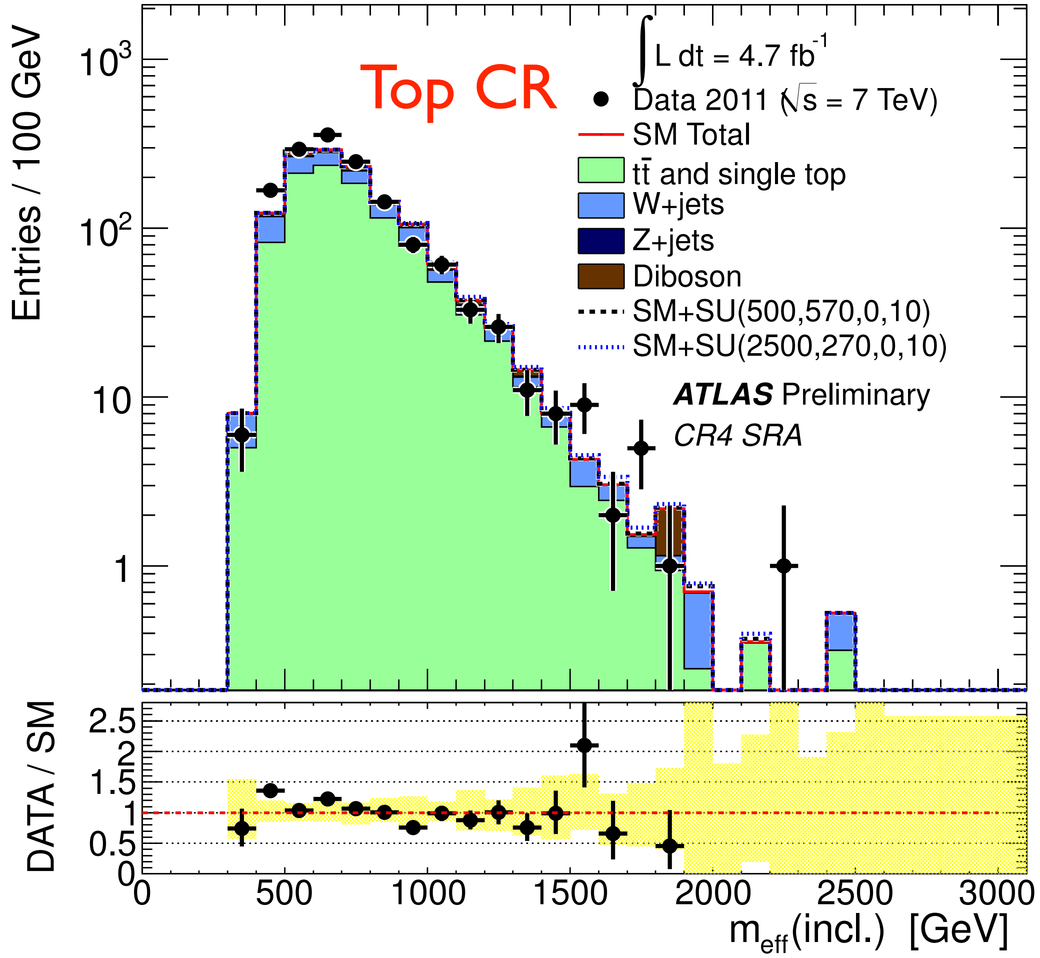
⟷ Control region-signal region transfer factors

⟷ Control region-control region transfer factors

W+jet and Top Control Regions

- W+jet and top CRs contain event with an isolated lepton
  - Transverse mass in (30, 100) GeV
  - With b-tagged->top CR
  - Without b-tagged->W CR
  - Lepton are treated as jets
- Transfer factor from MC simulation (Alpgen)





- Yellow bands are JES, JER and PileUp uncertainties

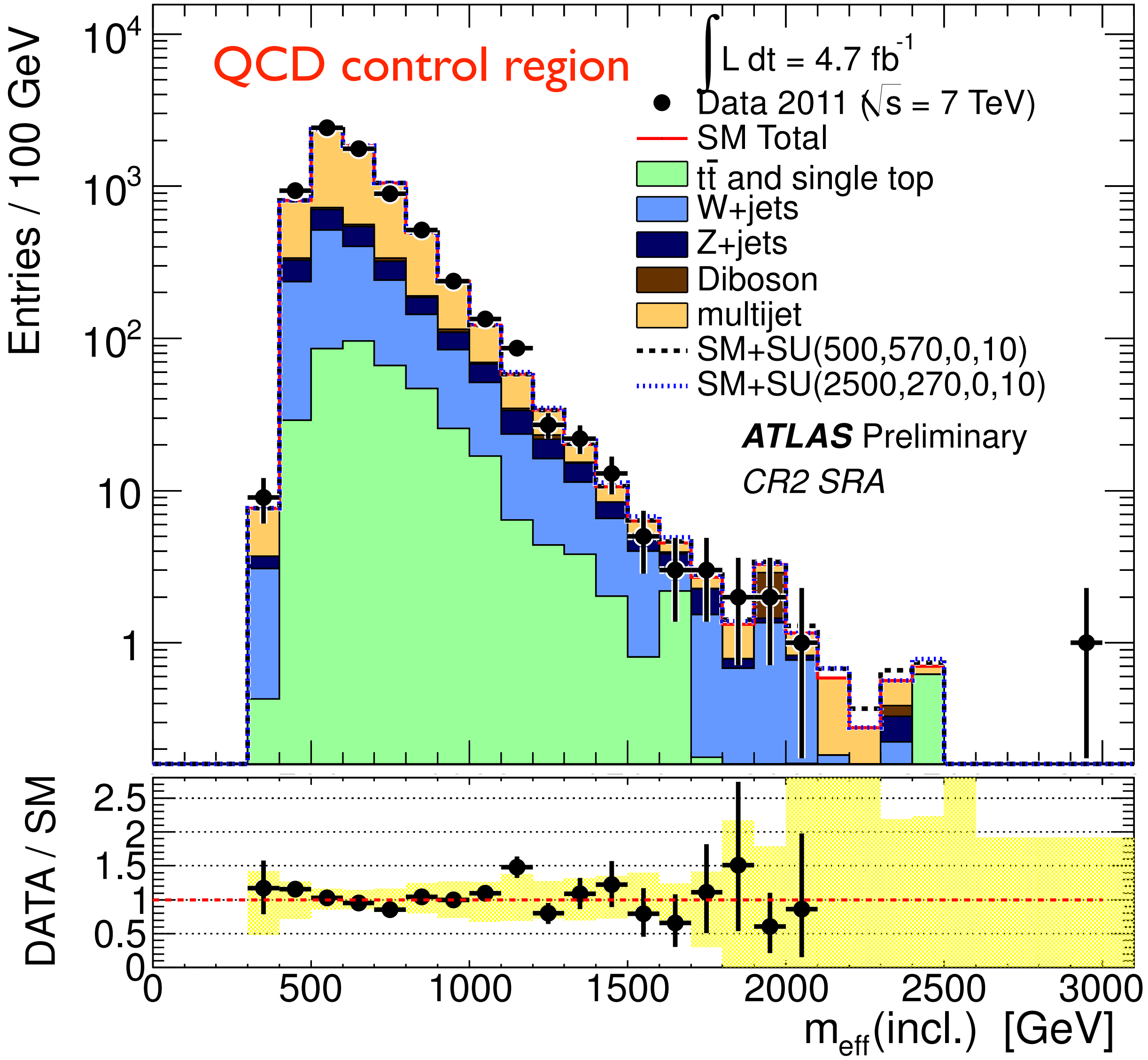
QCD Multijet Control Region

- Control region is defined by reversed ΔΦ cut

$$\Delta\phi(j_i, E_{\mathrm{T}}^{\mathrm{miss}}) < 0.2 :$$

i={1,2,(3)}(A, A', B) /

$p_{\mathrm{T}} > 40$ GeV jets (C,D,E)



- Transfer factor is derived by data-driven jet smearing method
  - Select low E_T^{miss} seed events
  - Apply a jet respond function to four-vectors of jets in seed events -> generate high m_{eff} events
  - Recalculate the ΔΦ variable using smeared jets -> define QCD multijet transfer factor from low and high ΔΦ regions corresponding to CR and SR respectively

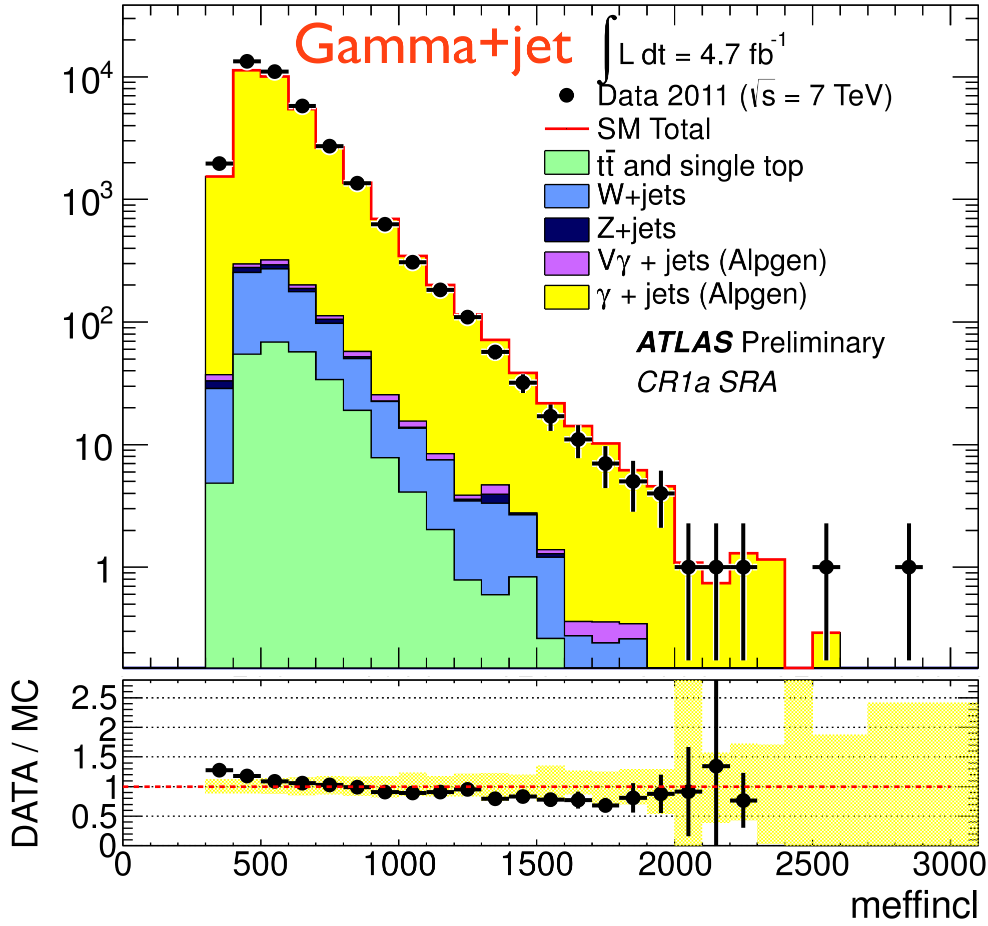
Z+jet Control Regions

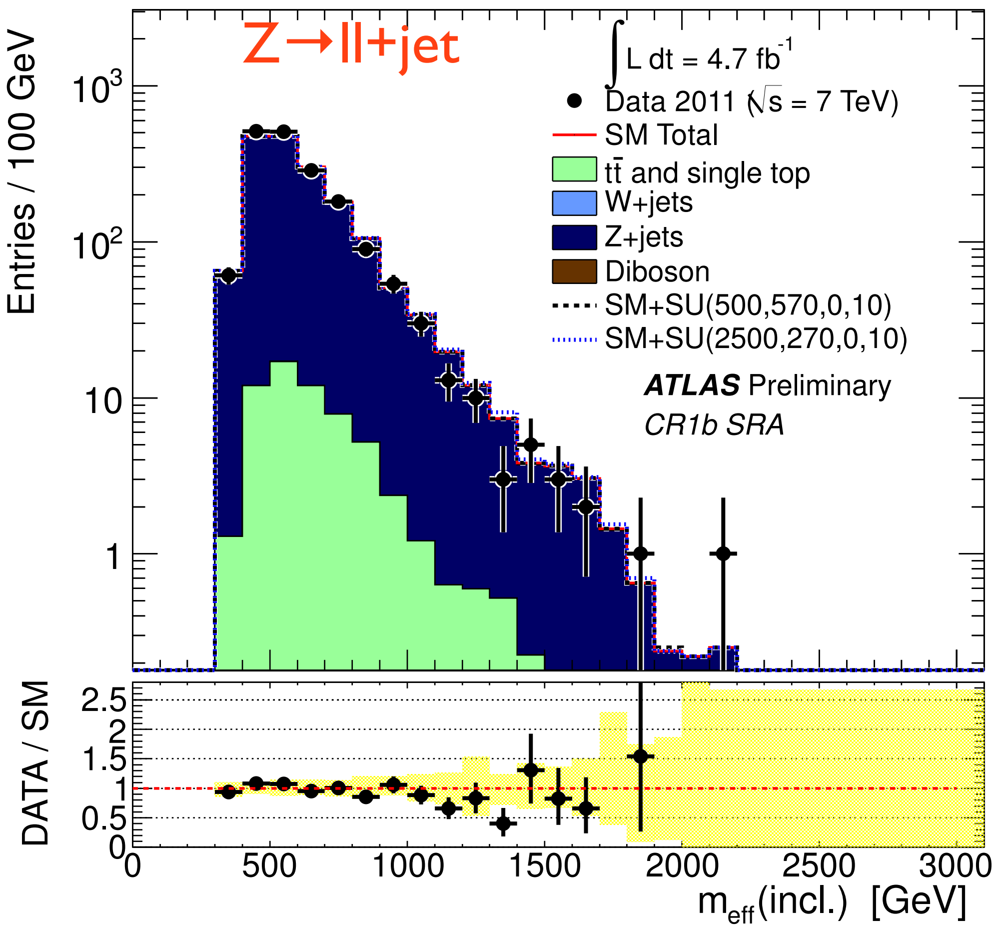
- Two control regions dedicated to Z+jet background
  - ▸ Gamma+jet events with photon treated as MET
  - ▸ Z->ll+jets events with Z treated as MET
- The transfer factors are derived from MC simulation
  - ▸ Gamma+jet $N^{Z_{\nu\nu}}\left(p_T^V, m_{\rm eff}(incl.)\right) = N^{\gamma}\left(p_T^V, m_{\rm eff}(incl.)\right) \cdot \boxed{\left[\frac{(1-f_{bkg})}{\varepsilon^{\gamma}(p_T^V)\cdot A^{\gamma}(p_T^V)} \cdot R_{Z/\gamma}(p_T^V)\cdot Br(Z\rightarrow\nu\nu)\right]}$

$$R_{Z/\gamma} = \frac{d\sigma(Z+\text{jets})/dp_{\rm T}}{d\sigma(\gamma+\text{jets})/dp_{\rm T}}$$

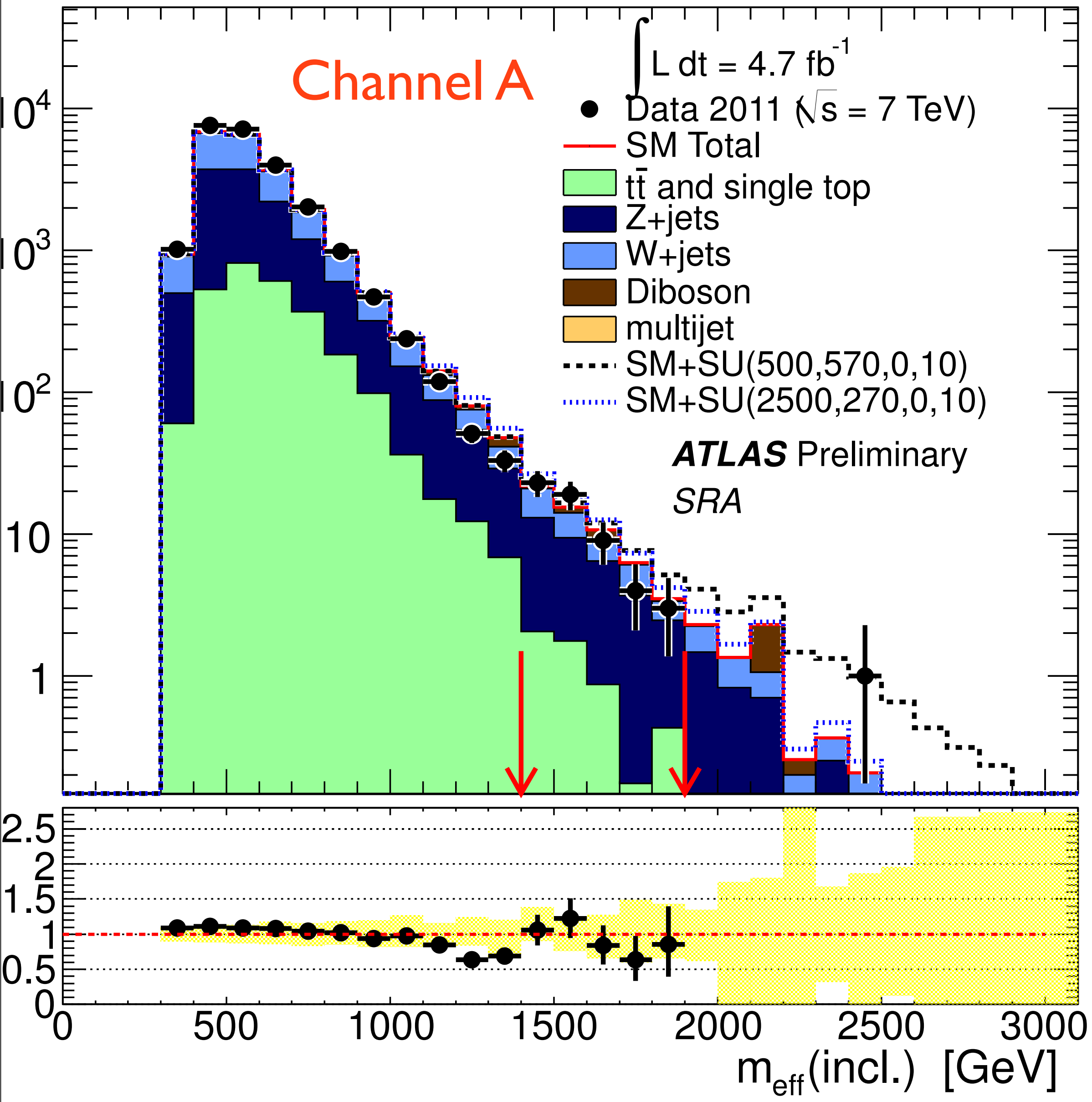
Transfer factor

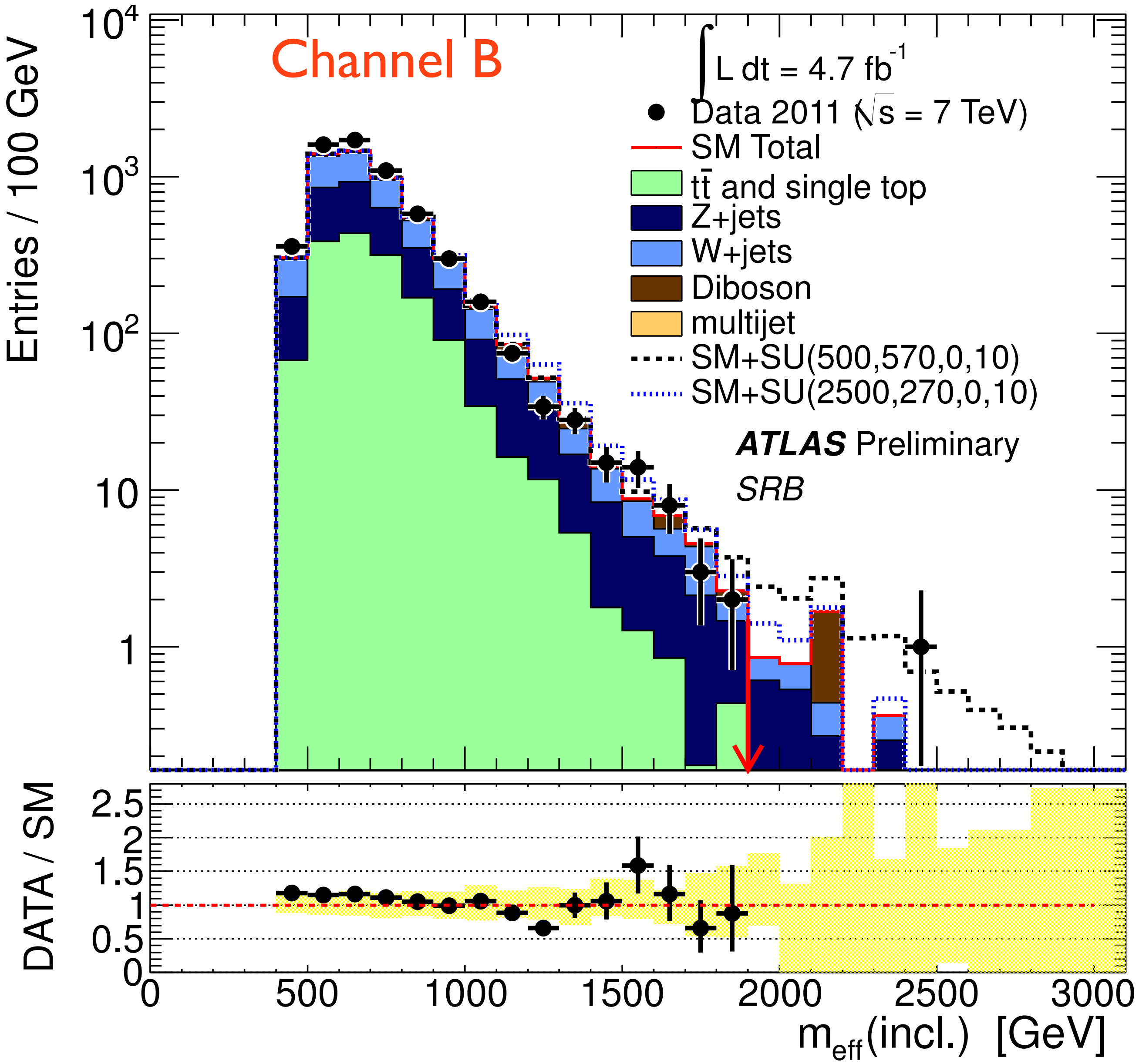
  - ▸ Z->ll+jet CR: ration of Z+jet in SR and Z->ll+jet in CR





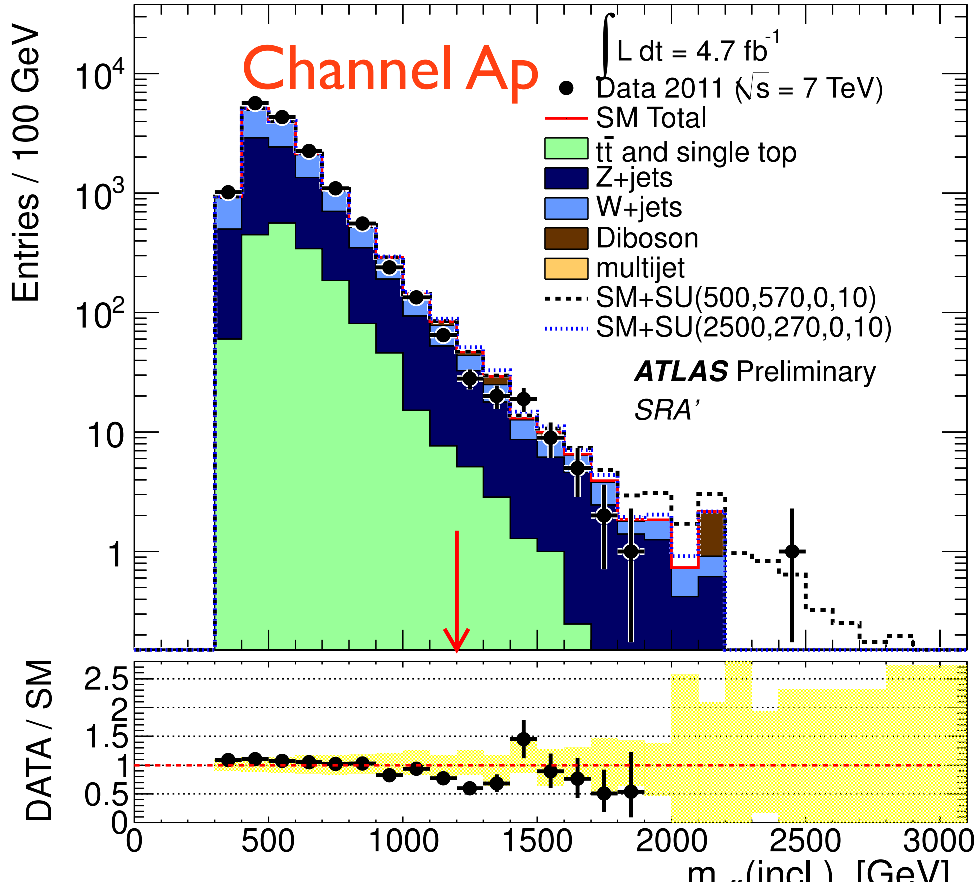
M_{eff} (incl.)Distribution in Signal Regions (I)

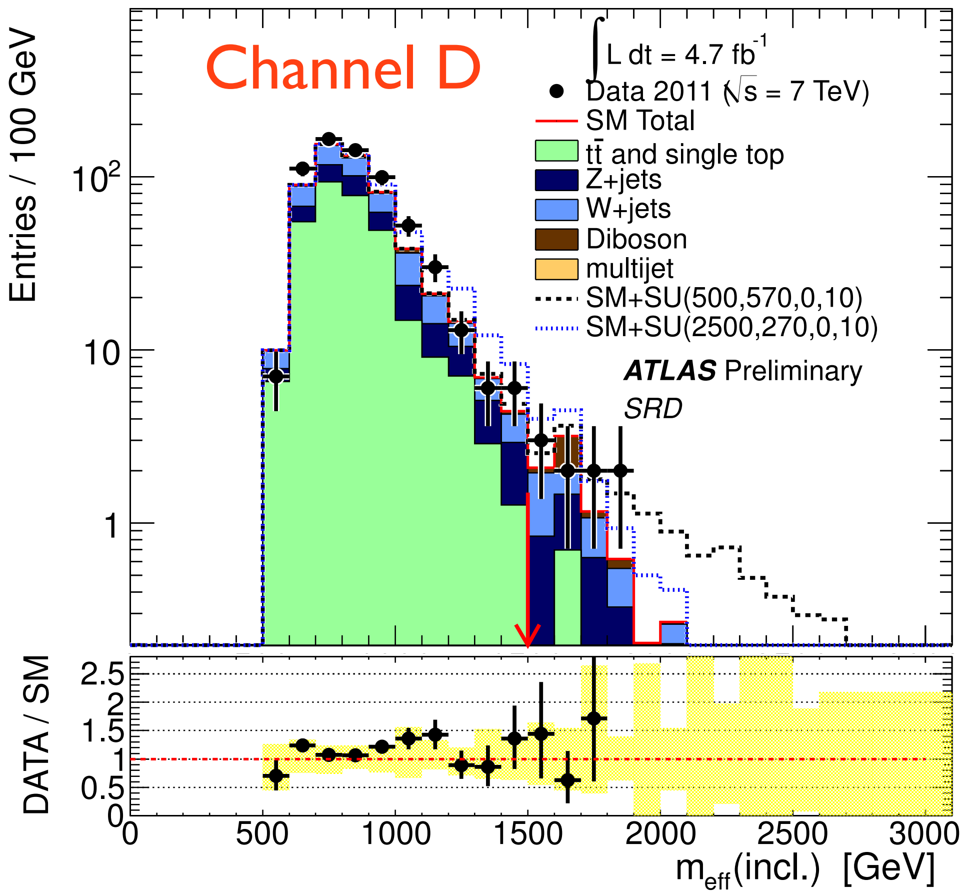


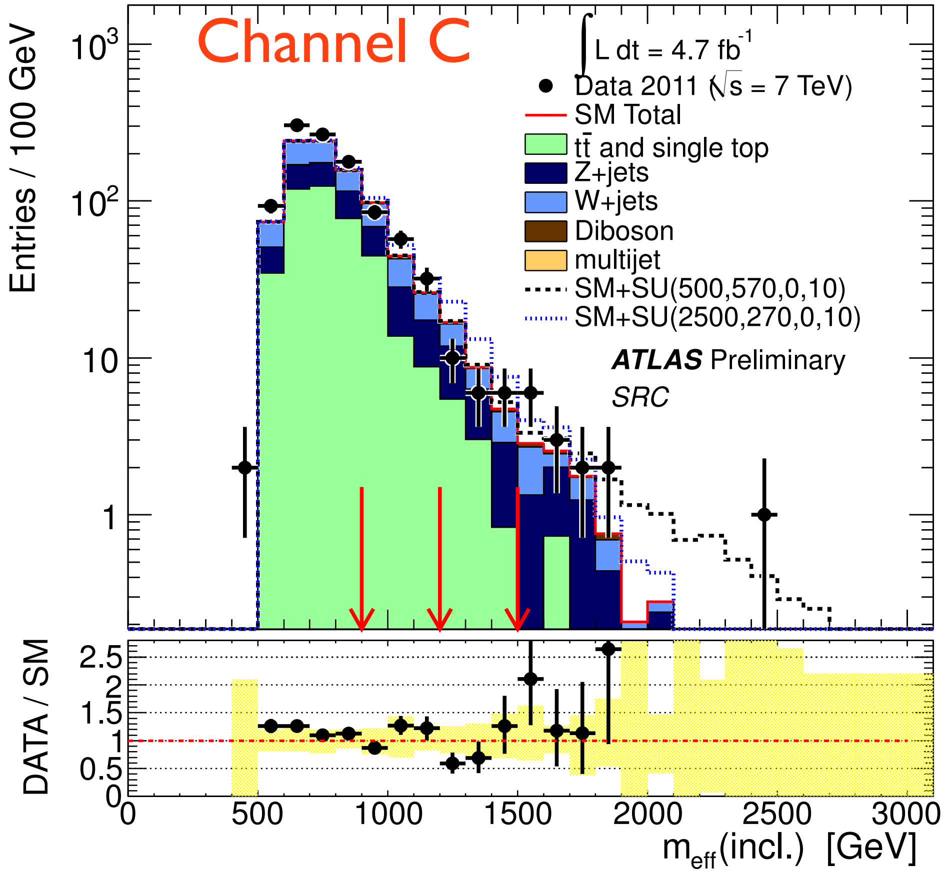


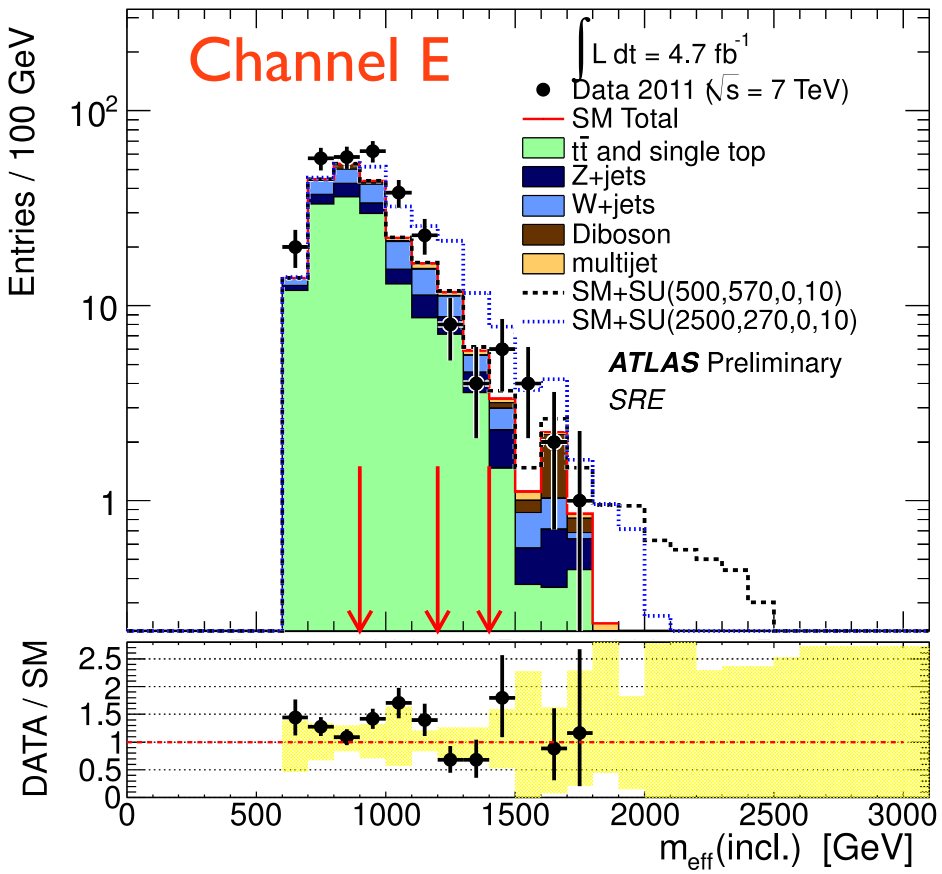
- Multijet background is from jet smearing results
- EWK, ttbar and single top backgrounds are from MC simulation normalized with luminosity and cross section
- Good agreement with data

M_{eff} (incl.)Distribution in Signal Regions (II)







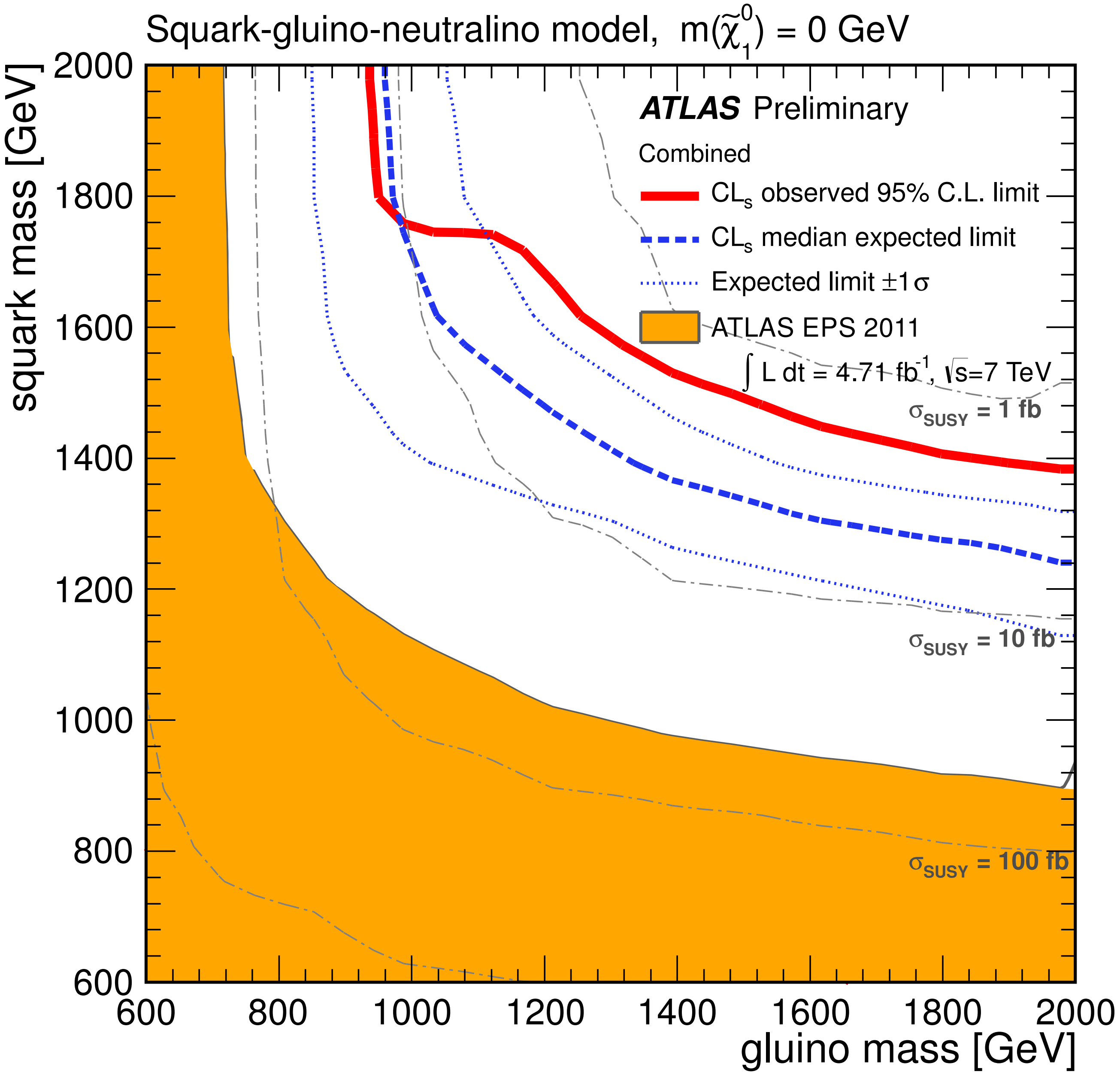


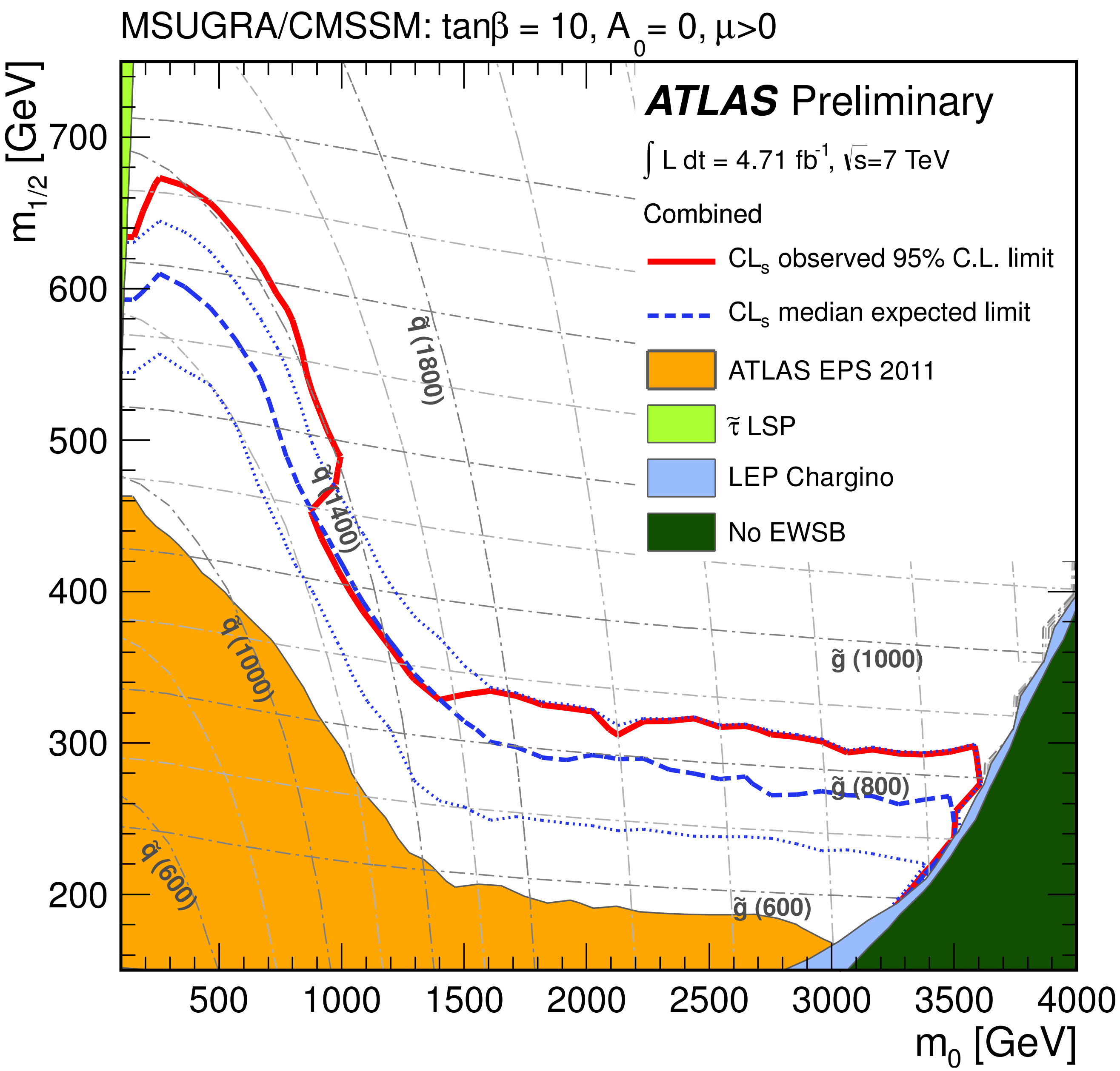
Background Estimation Results

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)
UL on N_{BSM}	$58(60^{44}_{83})$	$84(69^{52}_{93})$	$25(28^{20}_{39})$	$29(43^{32}_{60})$	$18(19^{14}_{27})$	$12(16^{12}_{23})$
UL on σ_{BSM} /(fb)	$12(13^{9.3}_{18})$	$18(15^{11}_{20})$	$5.3(6^{4.3}_{8.2})$	$6.2(9.2^{6.7}_{13})$	$3.7(4.1^{3}_{5.7})$	$2.5(3.5^{2.5}_{5})$

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)
UL on N_{BSM}	$2.9(6.1^{4.2}_{9})$	$3.1(5.5^{3.8}_{8.3})$	$16(11^{7.6}_{15})$	$10(8.9^{6.4}_{13})$	$12(12^{8.5}_{17})$
UL on σ_{BSM} /(fb)	$0.62(1.3^{0.89}_{1.9})$	$0.65(1.2^{0.8}_{1.8})$	$3.5(2.3^{1.6}_{3.2})$	$2.2(1.9^{1.4}_{2.7})$	$2.6(2.5^{1.8}_{3.5})$

Interpretation





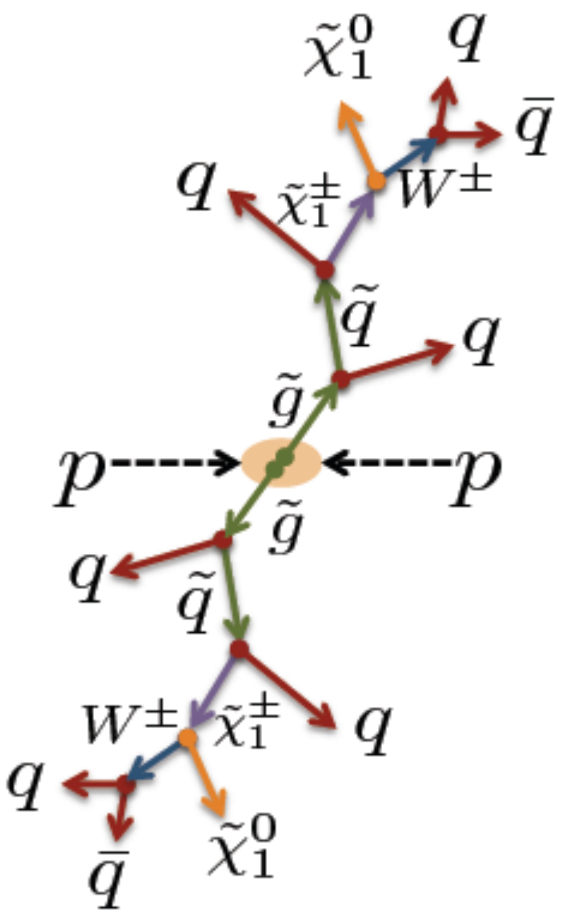
- Left plot: three-sparticle simplified model (two generation squarks with the same mass, gluino, LSP, other particles are out of reach, 5 TeV)
- Right plot: CMSSM/mSUGRA

6-9 jets analysis

Signature

- The analysis is an extension to 2-6 jet analysis
  - Sensitive to many-body decay and long decay chain (high m_0 in CMSSM/mSUGRA)
  - QCD multijet estimation with data-driven method
- Signal regions include 6-9 jets with high MET and no isolated lepton

Signal region	**7j55**	**8j55**	**9j55**	**6j80**	**7j80**	**8j80**
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
$E_{\mathrm{T}}^{\mathrm{miss}} / \sqrt{H_T}$	> 4 GeV$^{1/2}$					

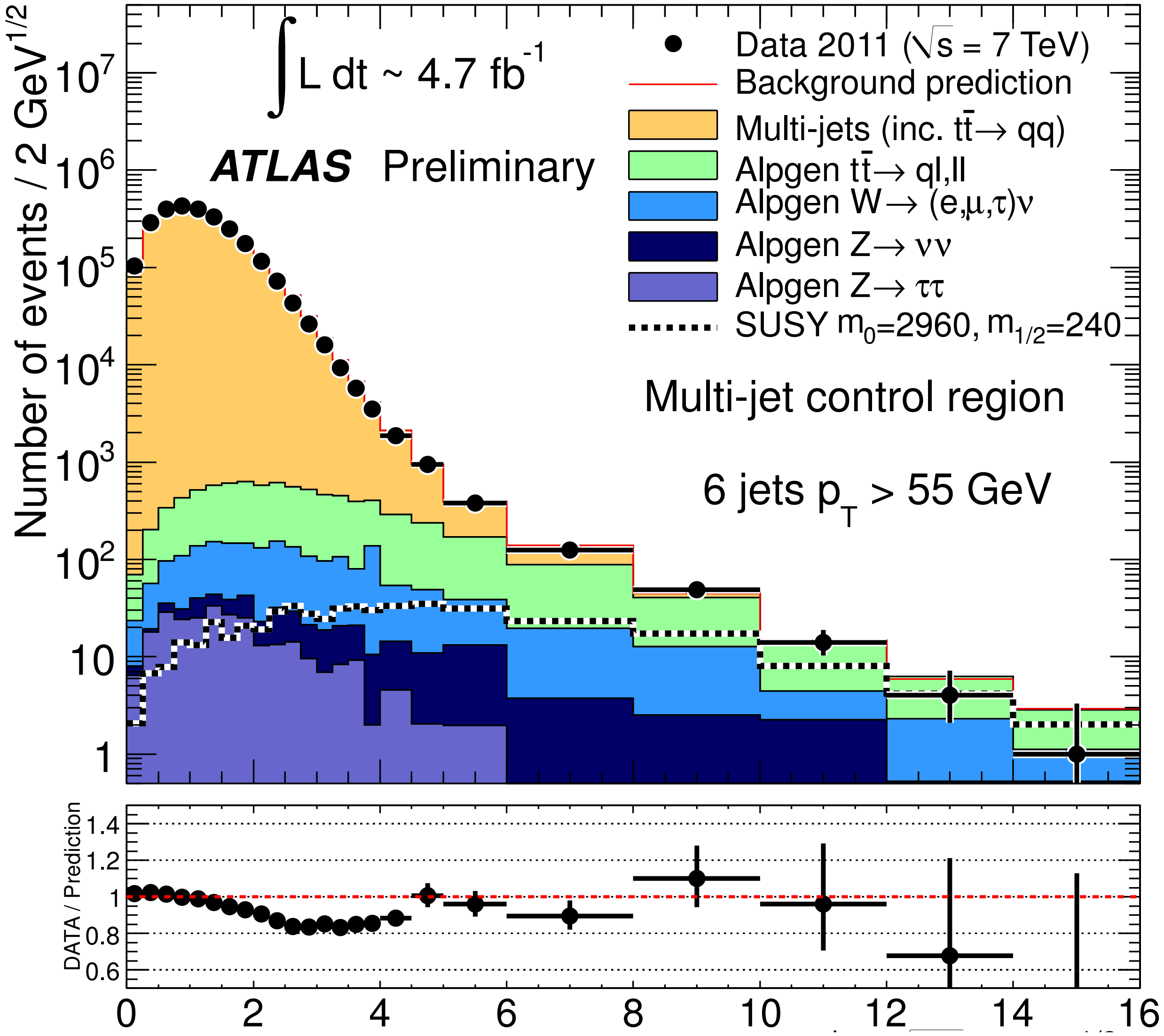


- Backgrounds: multijet (include ttbar all hadronic), leptonic backgrounds (W+jet, Z+jet and semi-,fully-leptonic ttbar)

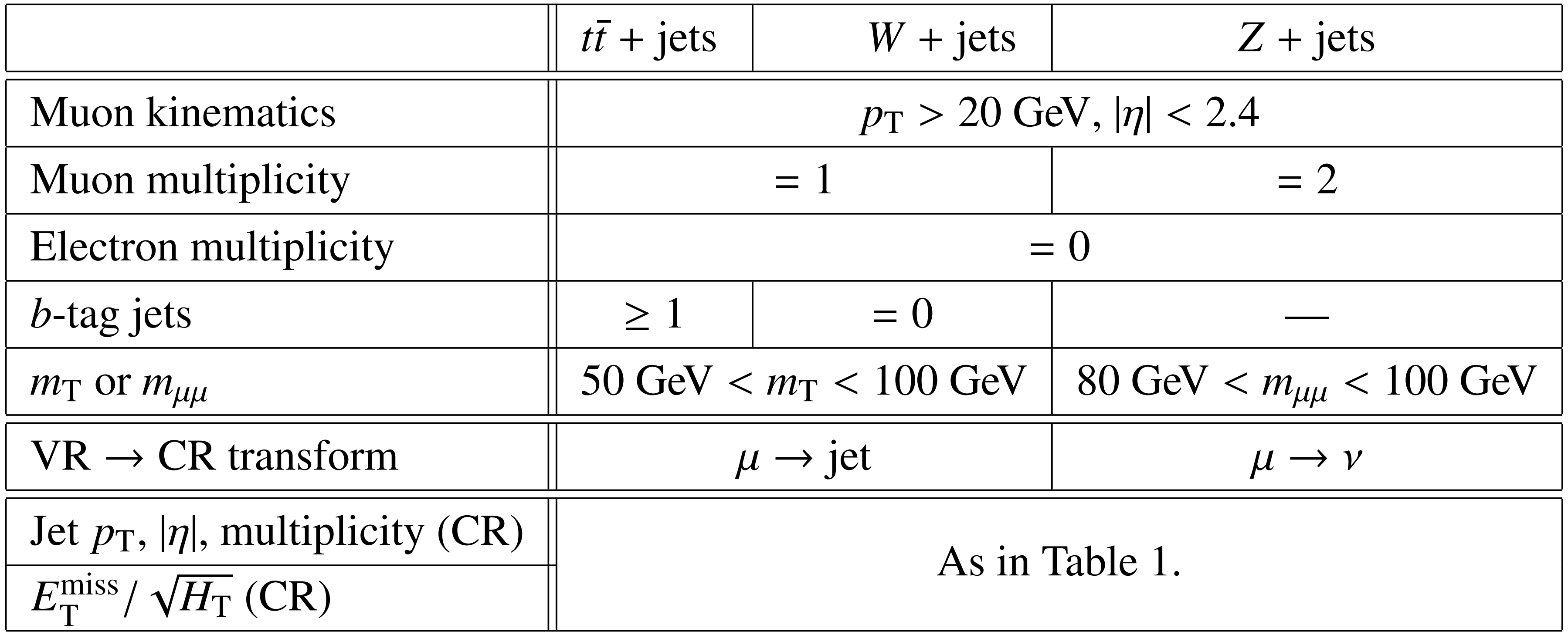
Multijet Background Estimation

- Data-drive template method
  - $E_T^{miss}/\sqrt{H_T} \sim E_T^{miss}$ significant: invariant to jet multiplicity
  - $E_T^{miss}/\sqrt{H_T}$ templates from low jet multiplicity (6 jets for 7-8-9 jet pT > 55 GeV and 5 jets for 6-7-8 jet pT > 80 GeV)
  - Low $E_T^{miss}/\sqrt{H_T}$ is used for template normalization (0-1.5)
  - Normalized template at high $E_T^{miss}/\sqrt{H_T}$ (>4) are estimated multijet background

- Validation: 6 jets pT>55 GeV data is compared with prediction using 5 jets template and normalization from 0-1.5



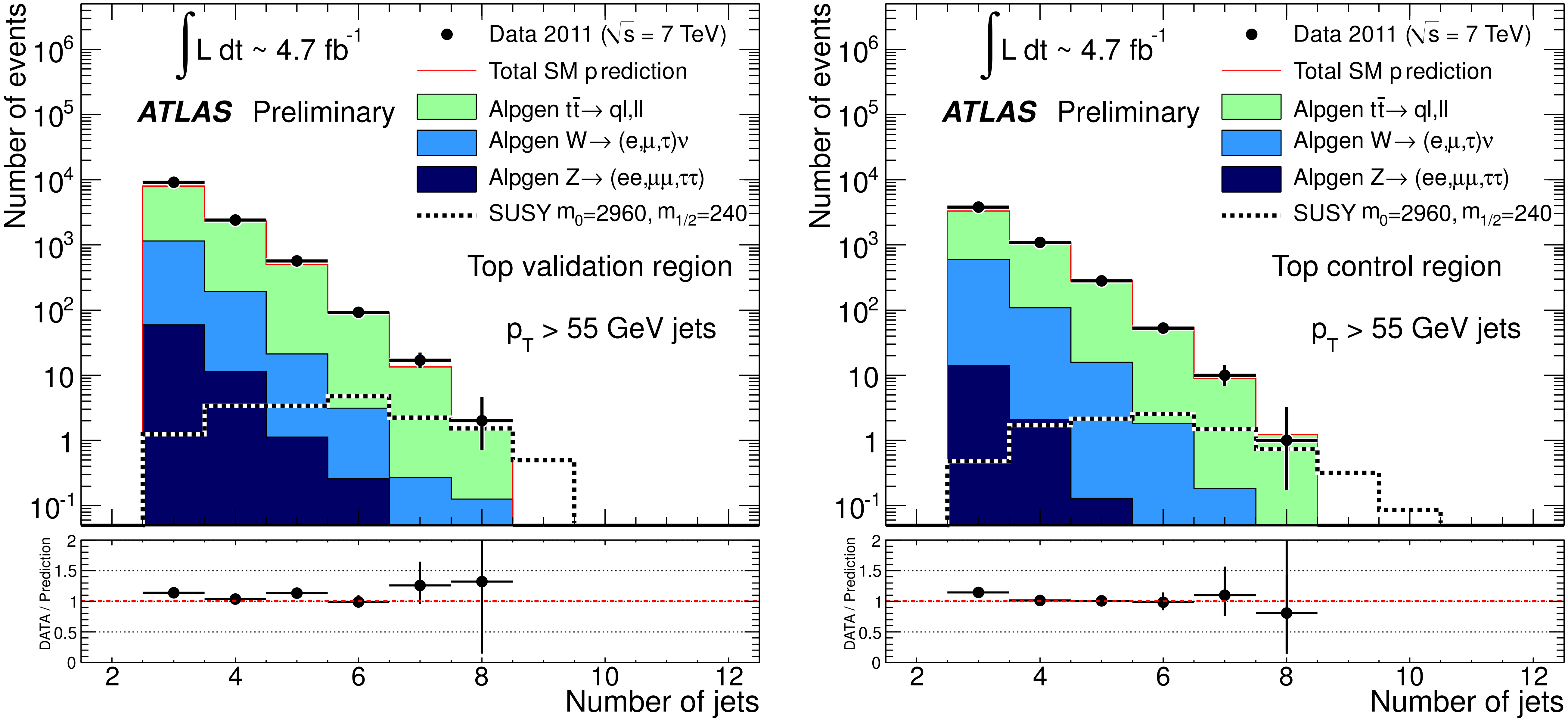
Leptonic Background



	$t\bar{t}$ + jets	W + jets	Z + jets
Muon kinematics	$p_{\mathrm{T}} > 20$ GeV, $\lvert\eta\rvert < 2.4$		
Muon multiplicity	= 1		= 2
Electron multiplicity	= 0		
b-tag jets	≥ 1	= 0	—
m_{T} or $m_{\mu\mu}$	50 GeV $< m_{\mathrm{T}} <$ 100 GeV		80 GeV $< m_{\mu\mu} <$ 100 GeV
VR → CR transform	$\mu \rightarrow$ jet		$\mu \rightarrow \nu$
Jet p_{T}, $\lvert\eta\rvert$, multiplicity (CR)	As in Table 1.		
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ (CR)			

- Validation regions (VR) and CRs are formed mostly by requiring leptons
- Use transfer factor between CRs and SRs estimated in MC simulation to estimate the backgrounds: background = transfer factor * number of data in CRs.
- ttbar control region: mostly coming from tau decay, muon is used to mimic the jet (njet increase 1 if muon pT > jet pT threshold, muon is included in $E_T^{miss}/\sqrt{H_T}$ calculation)
- W+jet CRs: veto b-jet

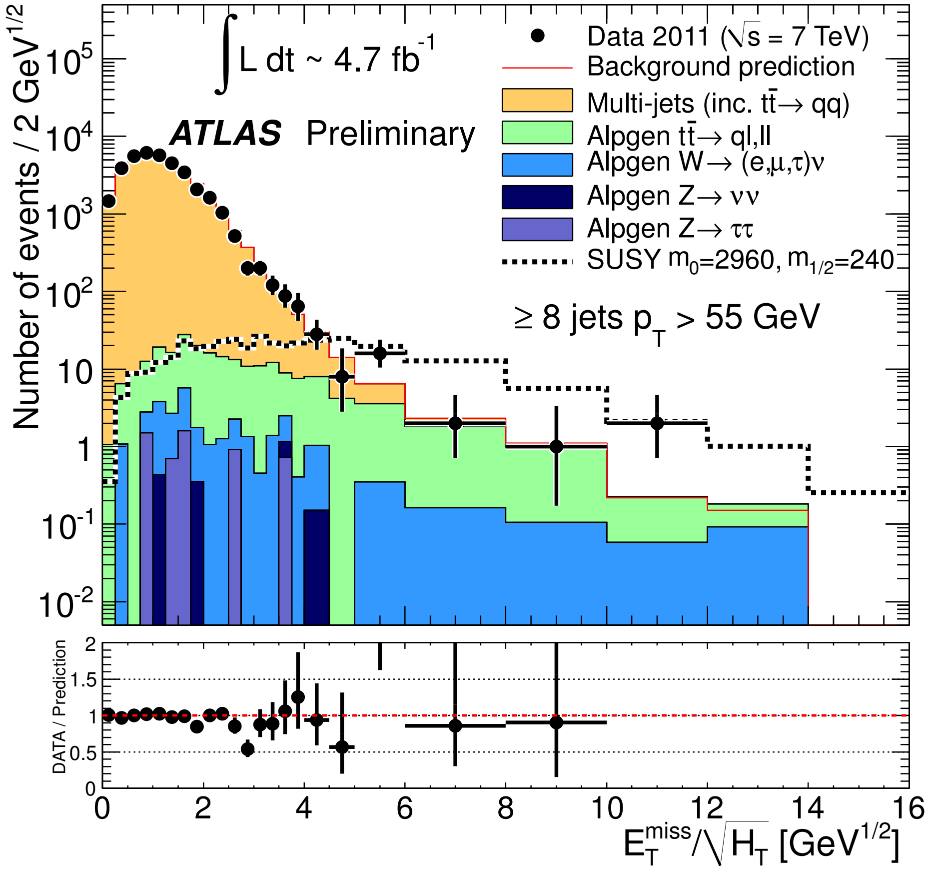
Top Validation and Control Region



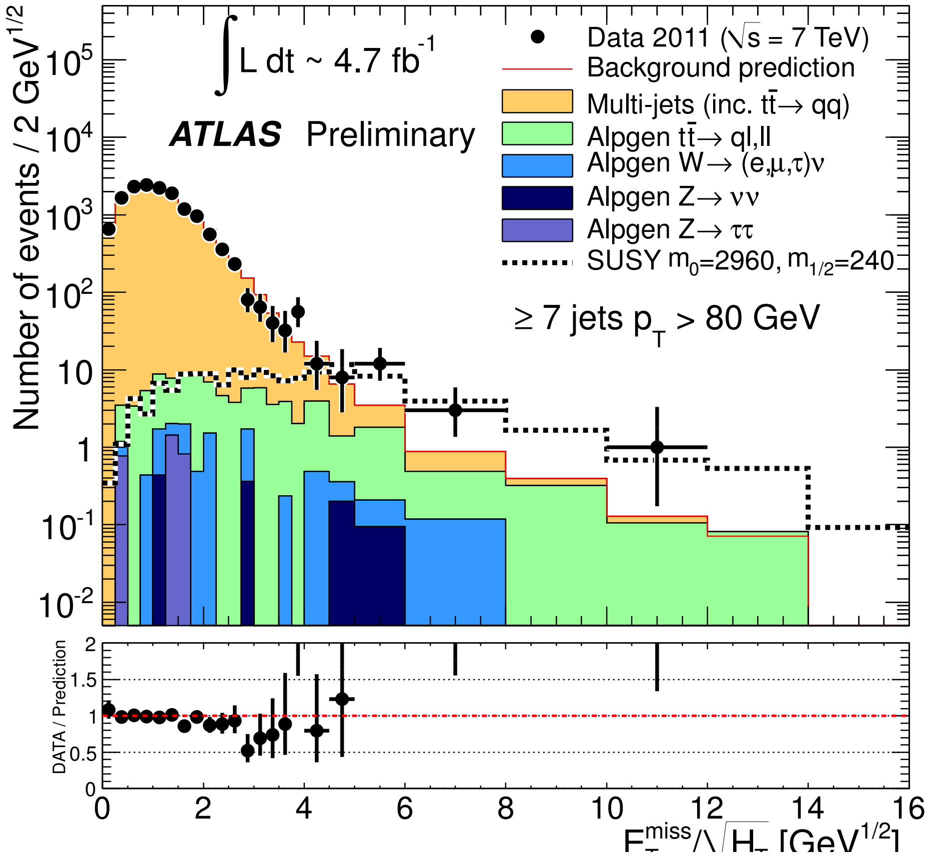
- Standard Model predictions are from MC simulation, normalized to luminosity and cross section
- Good agreement with observed data

Background Estimation Results

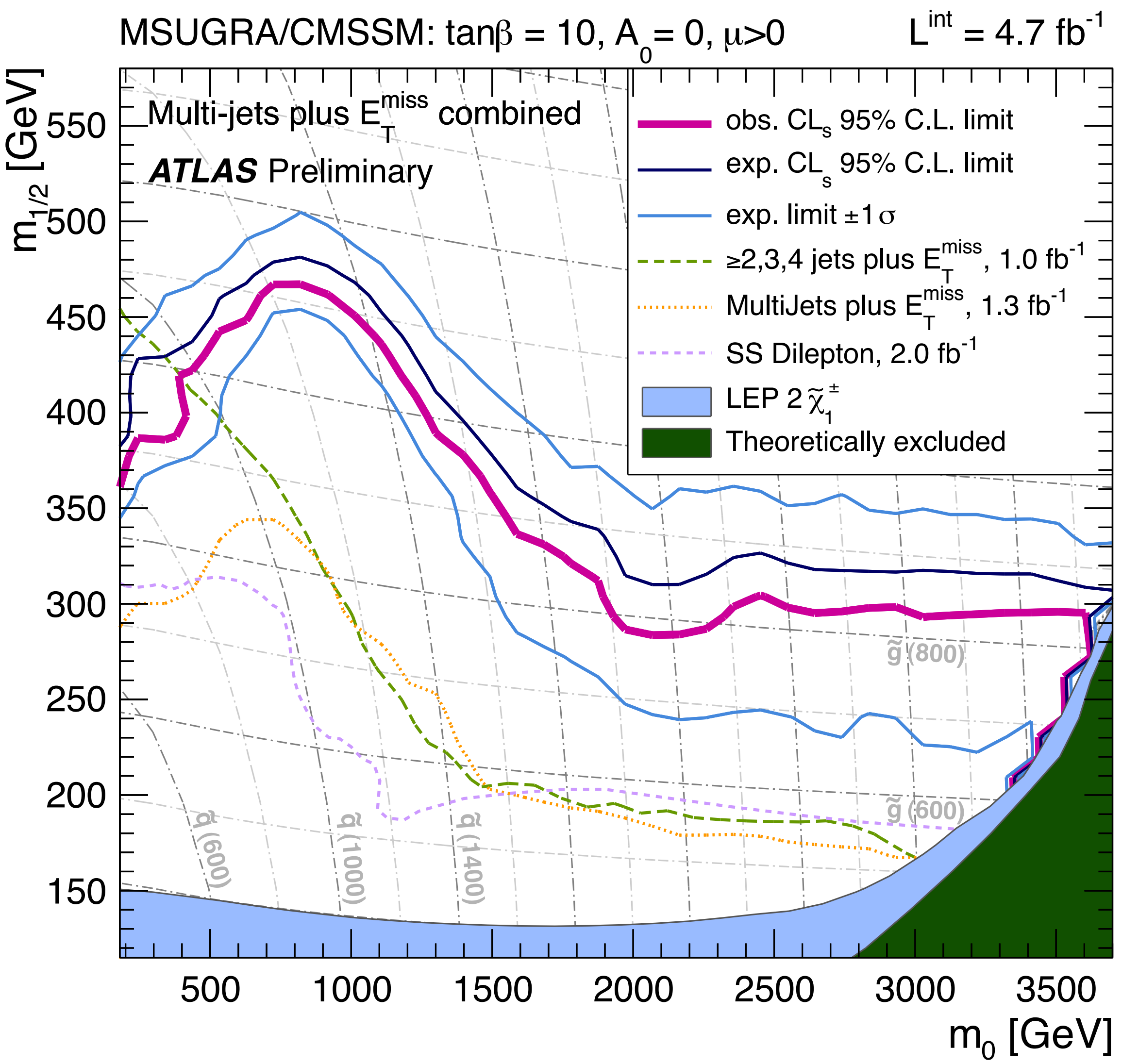
Signal region	**7j55**	**8j55**	**9j55**	**6j80**	**7j80**	**8j80**
Multi-jets	91±20	10±3	1.2±0.4	67±12	5.4±1.7	0.42±0.16
$t\bar{t} \to q\ell, \ell\ell$	55±18	5.7±6.0	0.70±0.72	24±13	2.8±1.8	0.38±0.40
W + jets	18±11	0.81±0.72	0+0.13	13±10	0.34±0.21	0+0.06
Z + jets	2.7±1.6	0.05±0.19	0+0.12	2.7±2.9	0.10±0.17	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

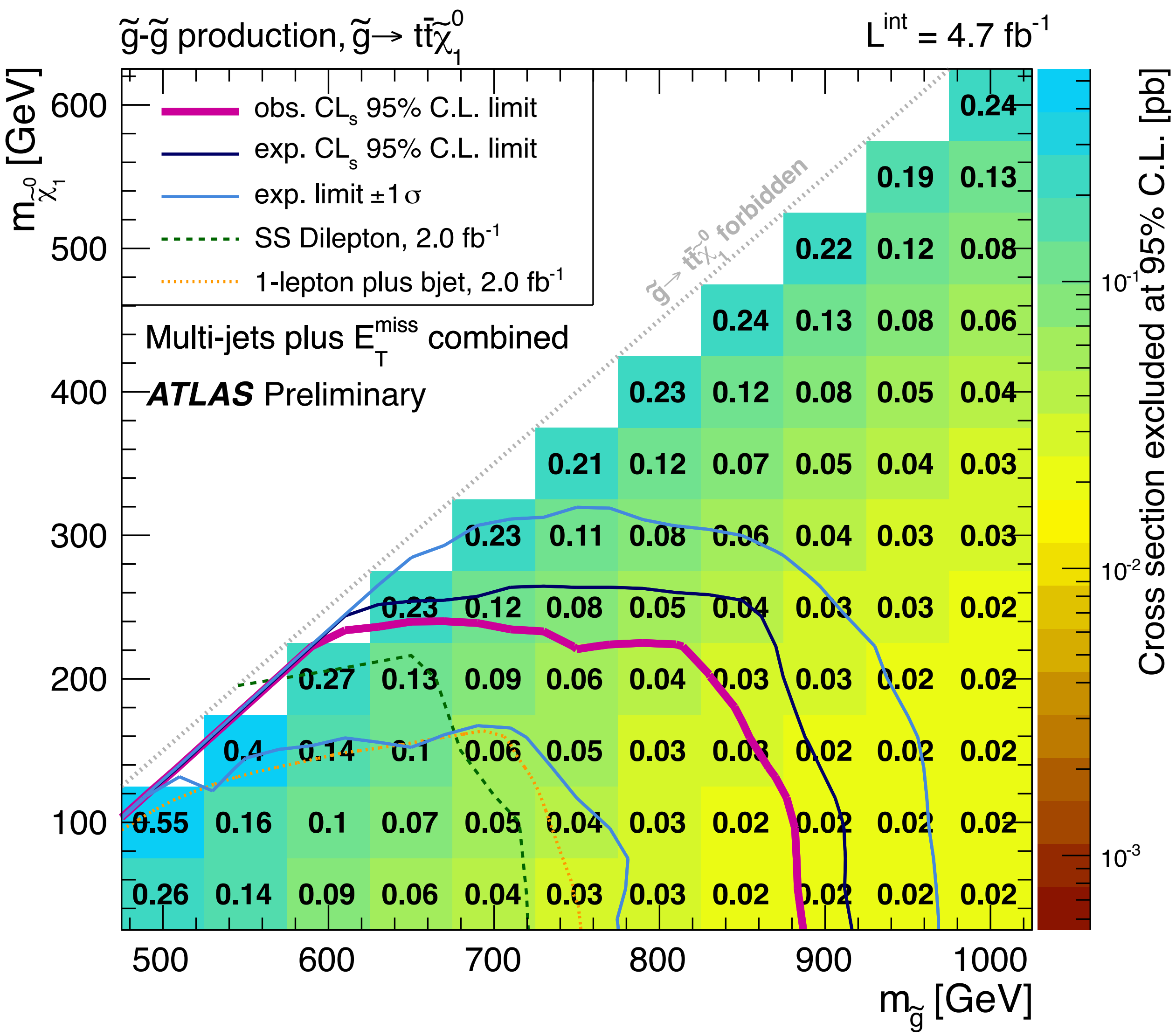


- No significant excess found



Interpretation



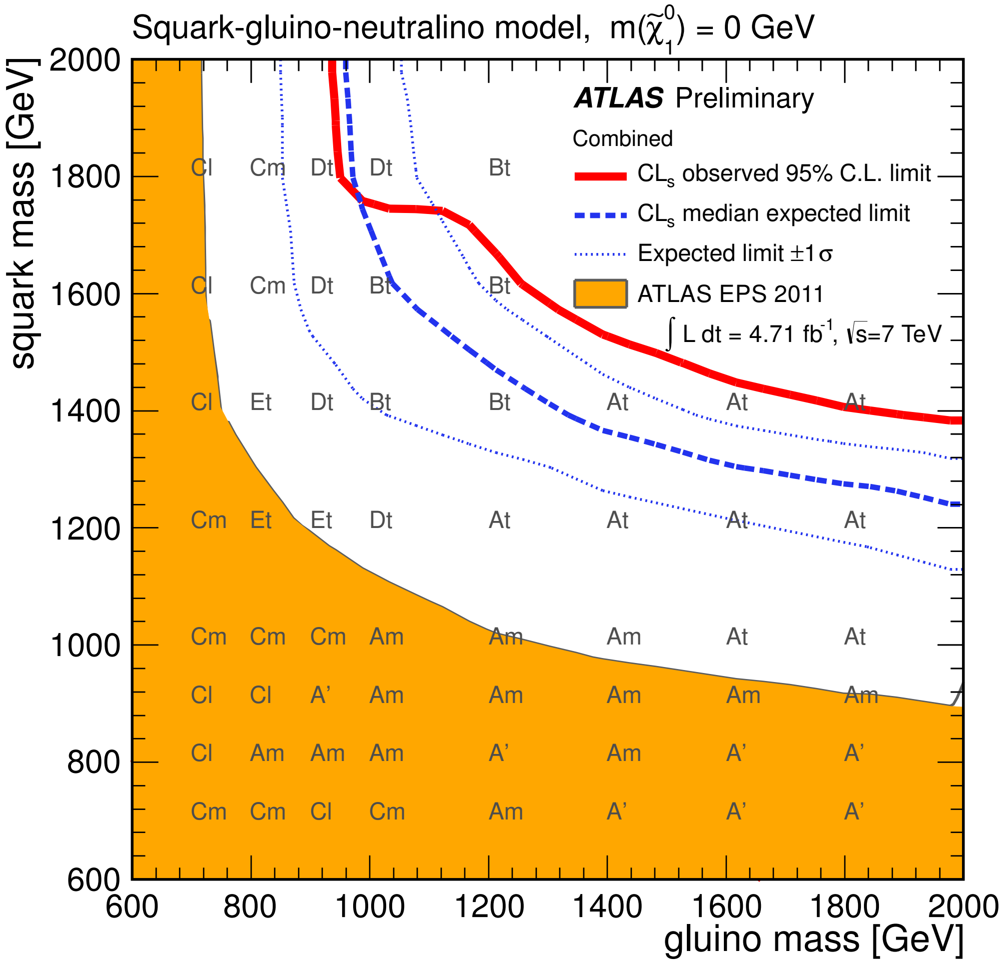


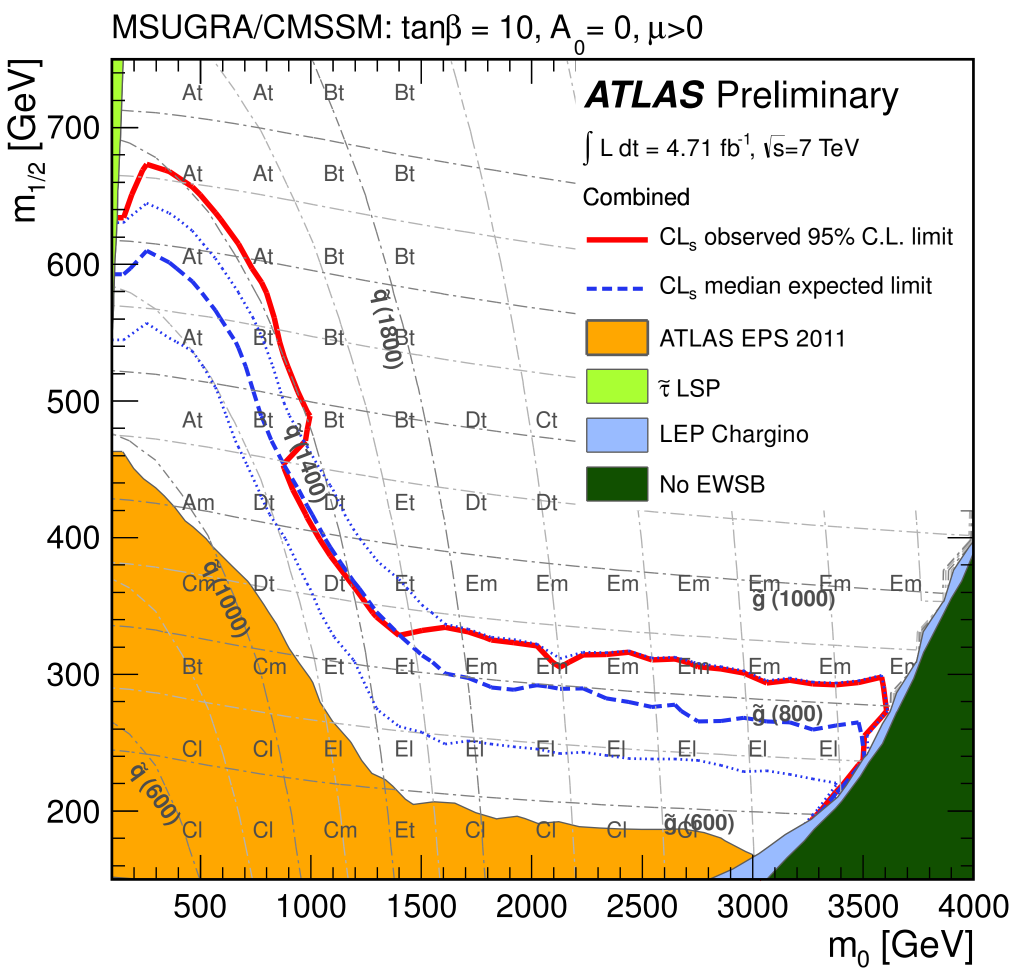
- Left: a slide in MSUGRA/CMSSM parameter space. Combined exclusion takes the best exclusions from a SRs at each parameter point. At large m_0 (2TeV), limit is independent with squark mass and the gluino mass limit is ~850 GeV
- Right: simplified model with only a gluino and a neutralino within kinematic reach. Gluino decays all to ttbar+LSP. m_g>880 GeV for m_{LSP} up to 100 GeV

Conclusions

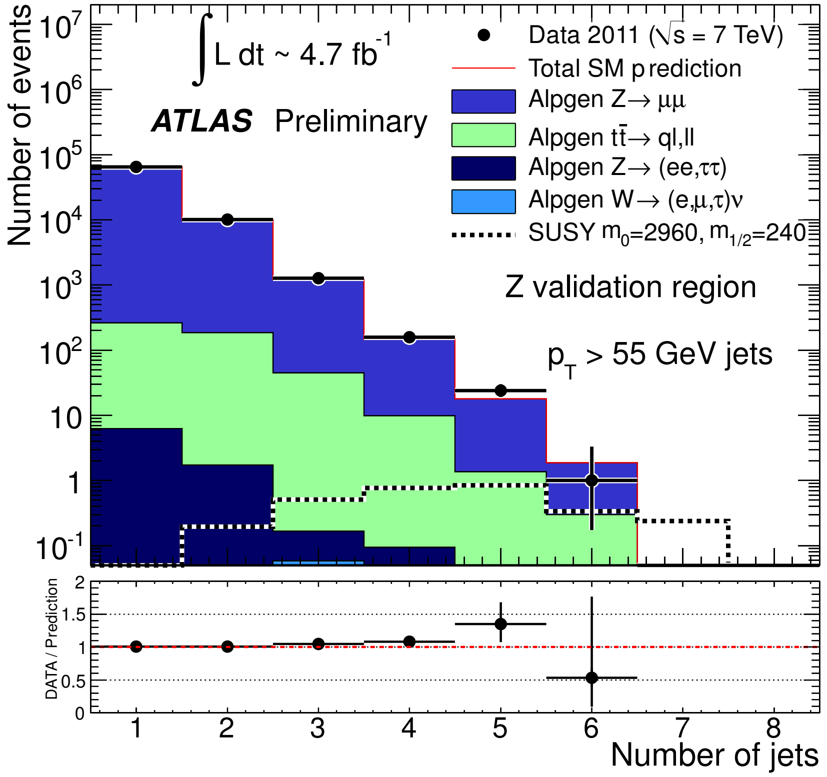
- ATLAS has performed extensive search for strong interaction squark and gluino production in jet+MET channel
- No significant excess is observed in 4.7 fb^{-1} of data at 7 TeV
- 95% C.L. limits on parameters of simplified and CMSSM/mSUGRA model are set.
  - 2-6 jets analysis:
    - CMSSW/mSUGRA: gluino and squark with equal masses are excluded below 1400 GeV
    - Simplified model: gluino mass below 940 GeV and squark mass below 1380 GeV is excluded.
  - 7-9 jets analysis:
    - CMSSM/mSUGRA: gluino mass > 850 GeV at large m_0
    - Simplified model (ttbar pairs at final state): gluino mass > 880 GeV for neutralino mass < 100 GeV

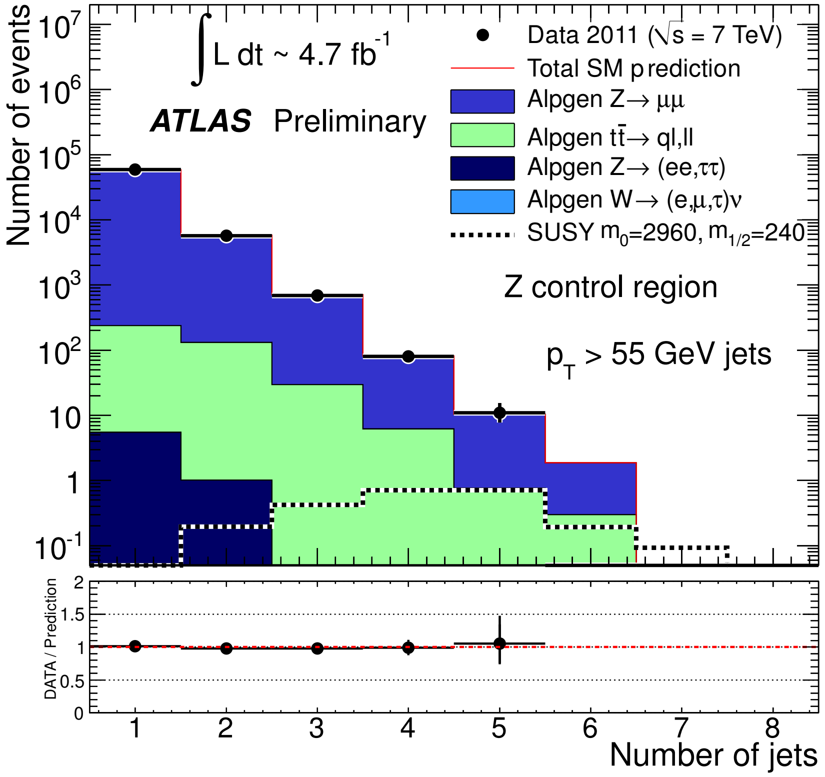
Backups

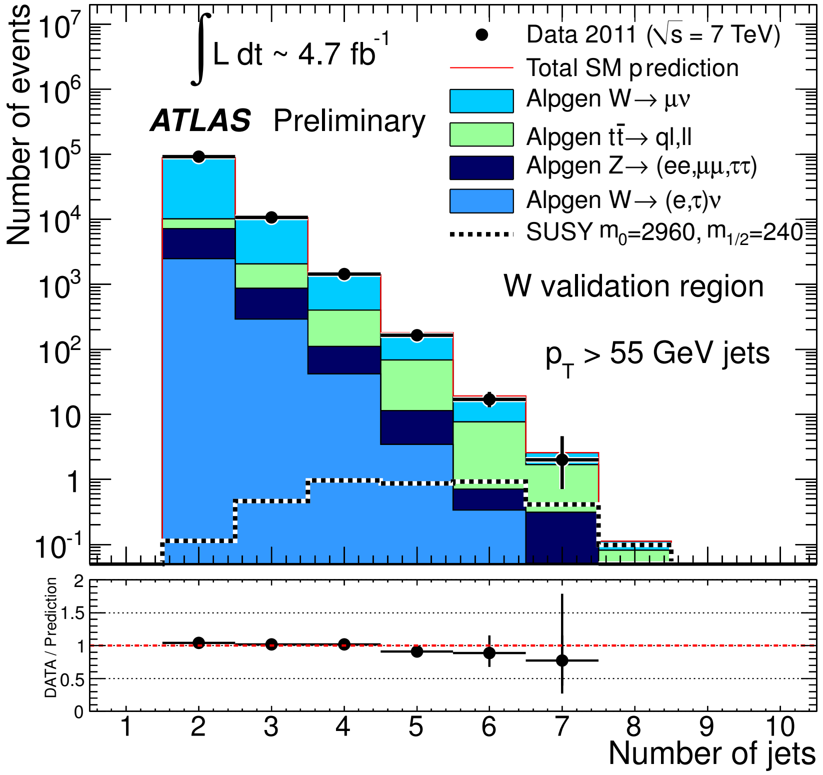

Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0)$ = 0 GeV
ATLAS Preliminary
Combined
CL$_s$ observed 95% C.L. limit
CL$_s$ median expected limit
Expected limit ±1σ
ATLAS EPS 2011
∫ L dt = 4.71 fb^{-1}, √s=7 TeV
squark mass [GeV]
gluino mass [GeV]
2000
1800
1600
1400
1200
1000
800
600
600
800
1000
1200
1400
1600
1800
2000

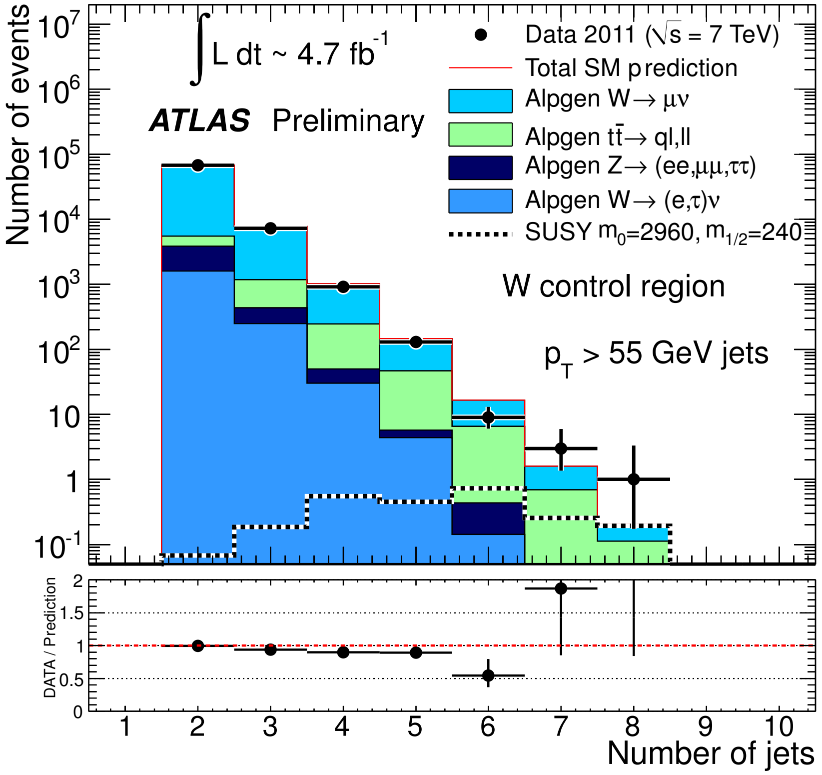

MSUGRA/CMSSM: tanβ = 10, A_0 = 0, μ>0
ATLAS Preliminary
∫ L dt = 4.71 fb^{-1}, √s=7 TeV
Combined
CL$_s$ observed 95% C.L. limit
CL$_s$ median expected limit
ATLAS EPS 2011
$\tilde{\tau}$ LSP
LEP Chargino
No EWSB
$m_{1/2}$ [GeV]
m_0 [GeV]
$\tilde{q}$ (1800)
$\tilde{q}$ (1400)
$\tilde{q}$ (1000)
$\tilde{q}$ (600)
$\tilde{g}$ (1000)
$\tilde{g}$ (800)
$\tilde{g}$ (600)
700
600
500
400
300
200
500
1000
1500
2000
2500
3000
3500
4000

Multijet Analysis: W and Z VRs and CRs









Multijet Analysis: Jet Multiplicity