Jets + missing E_T SUSY searches in ATLAS

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on behalf of the ATLAS collaboration

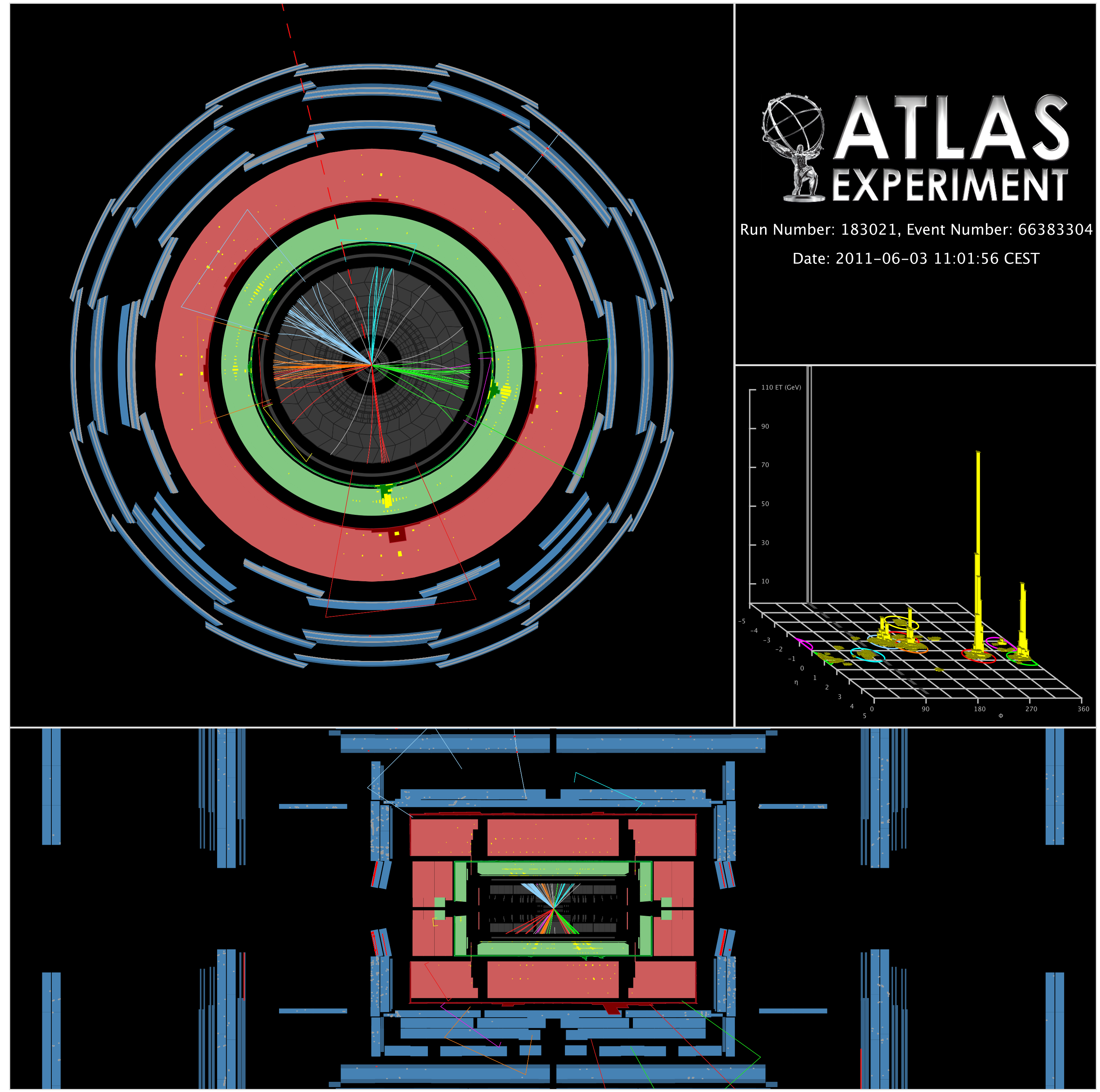
La Thuile 2012, 1 March

NIKHEF

ATLAS EXPERIMENT

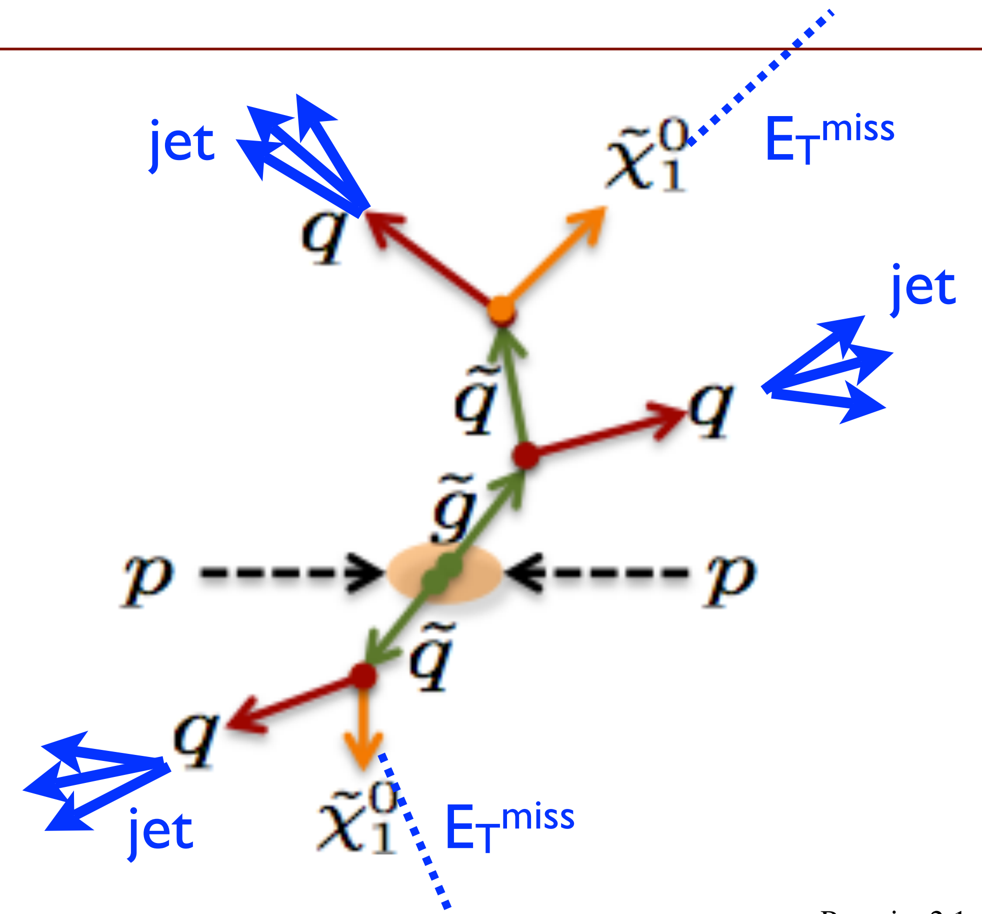
Introduction

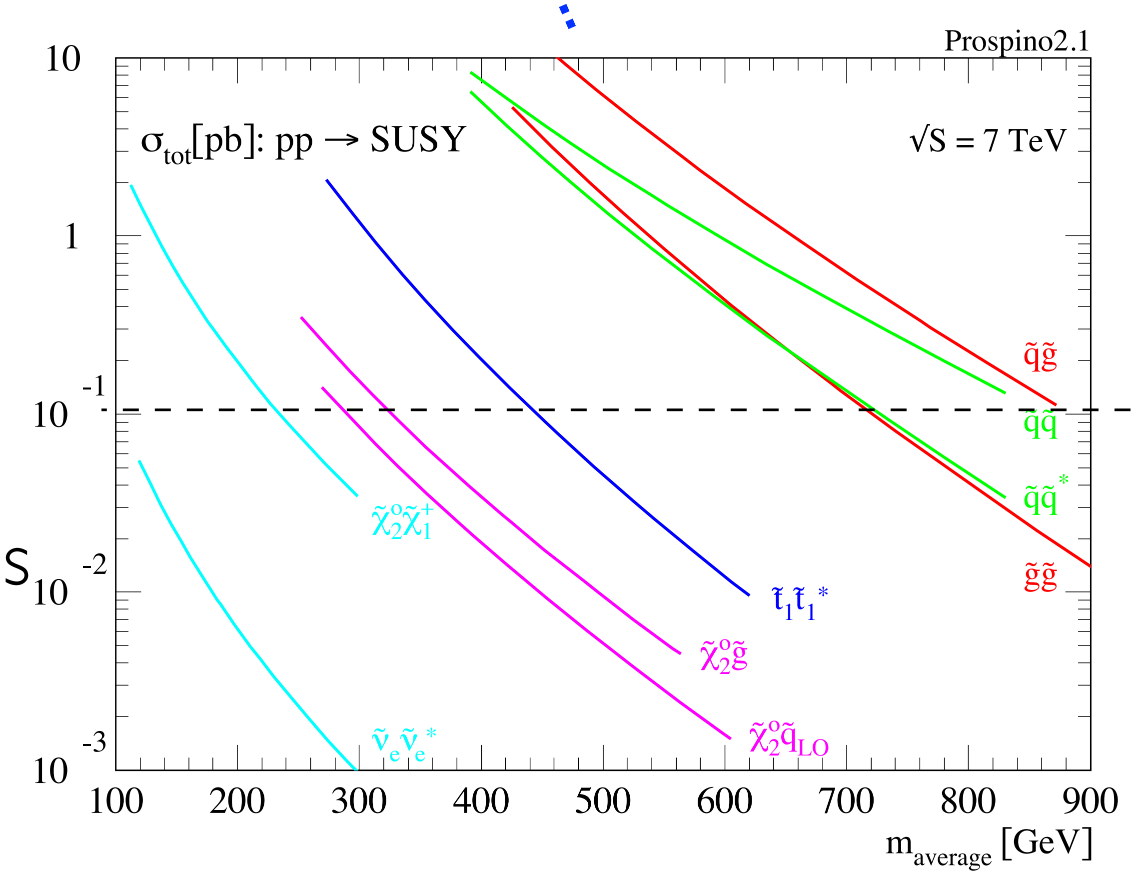
- Presenting ATLAS searches for **strongly produced** particles in final states with **jets and missing transverse momentum** using 7 TeV LHC collisions
    - Interpreted in various Supersymmetric models
- Data gathered up to summer 2011: > **1 fb^{-1}** for all presented analyses



Motivation

- Squarks and gluinos → quarks and gluons (+ charginos/neutralinos)
- R-parity conservation → stable light particle (LSP)
- Common signature: high-p_T jets, missing transverse energy
  - Additional leptons / photons / b-jets are possible from decays
  - This talk focusses on non-leptonic final states, with 2 analyses:
    - **2-4 jet inclusive**: $\tilde{q}\tilde{q}/ \tilde{g}\tilde{q}/\tilde{g}\tilde{g}$
    - **multijets** (≥6 jets): long decay chains (non-leptonic)

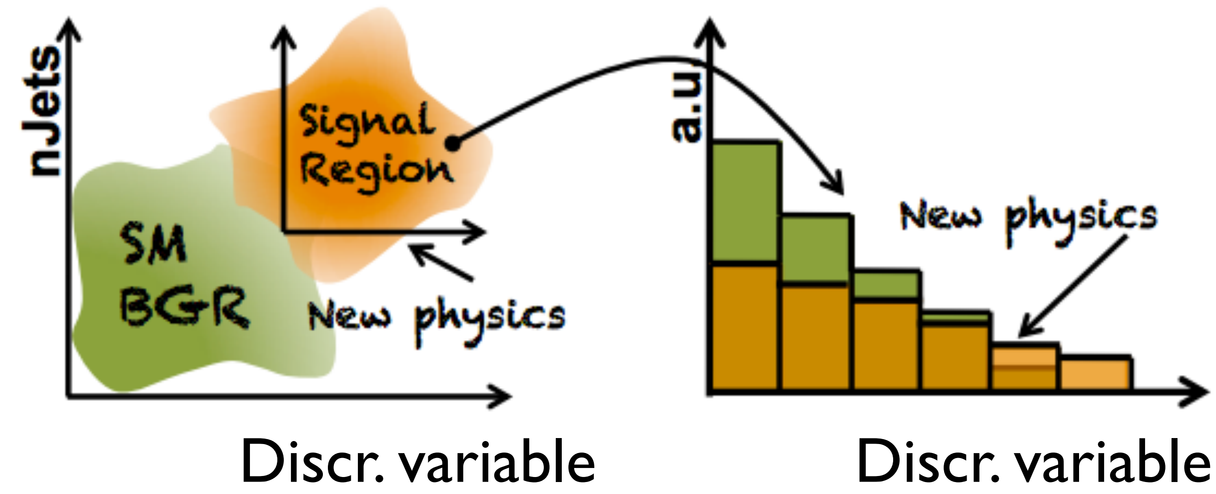


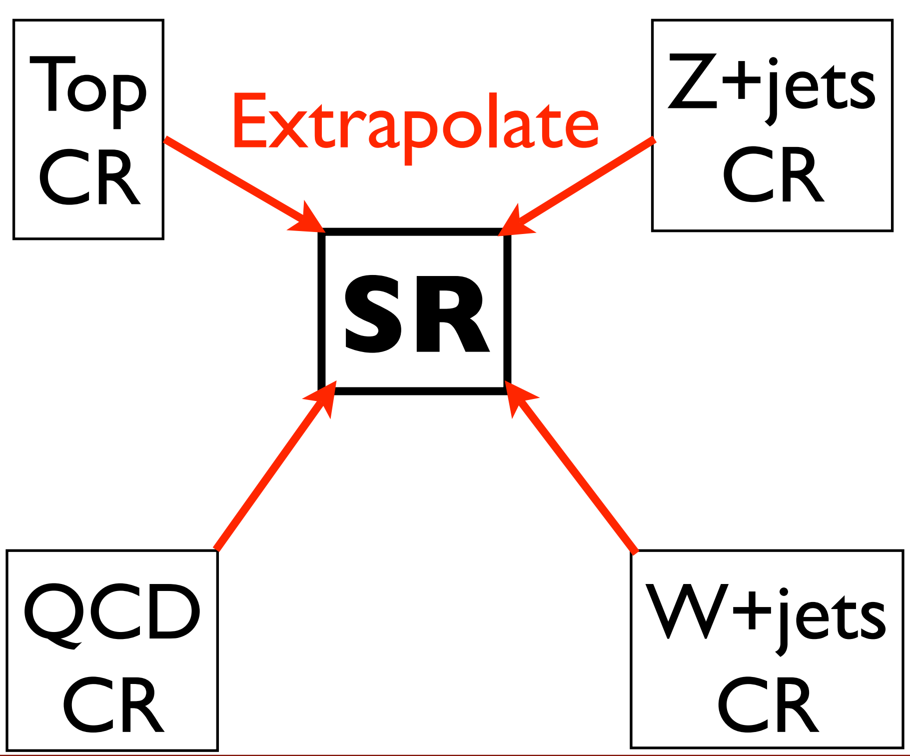


Analysis strategy

Analysis strategy follows same approach for both analyses

- Use a basic **cut and count analysis**:
  - Define several Signal Regions (SR) for the various interesting topologies





Background determination:

- (partially) data-driven: define Control Regions (CR), enriched in a particular background process
  - Extrapolate to SR to get background estimation
- Profile likelihood fit accounts for systematic uncertainties and (for limit setting) CR contamination by signal

2-4 jet inclusive

(L=1.04fb^{-1})

Signal regions

arXiv:1109.6572

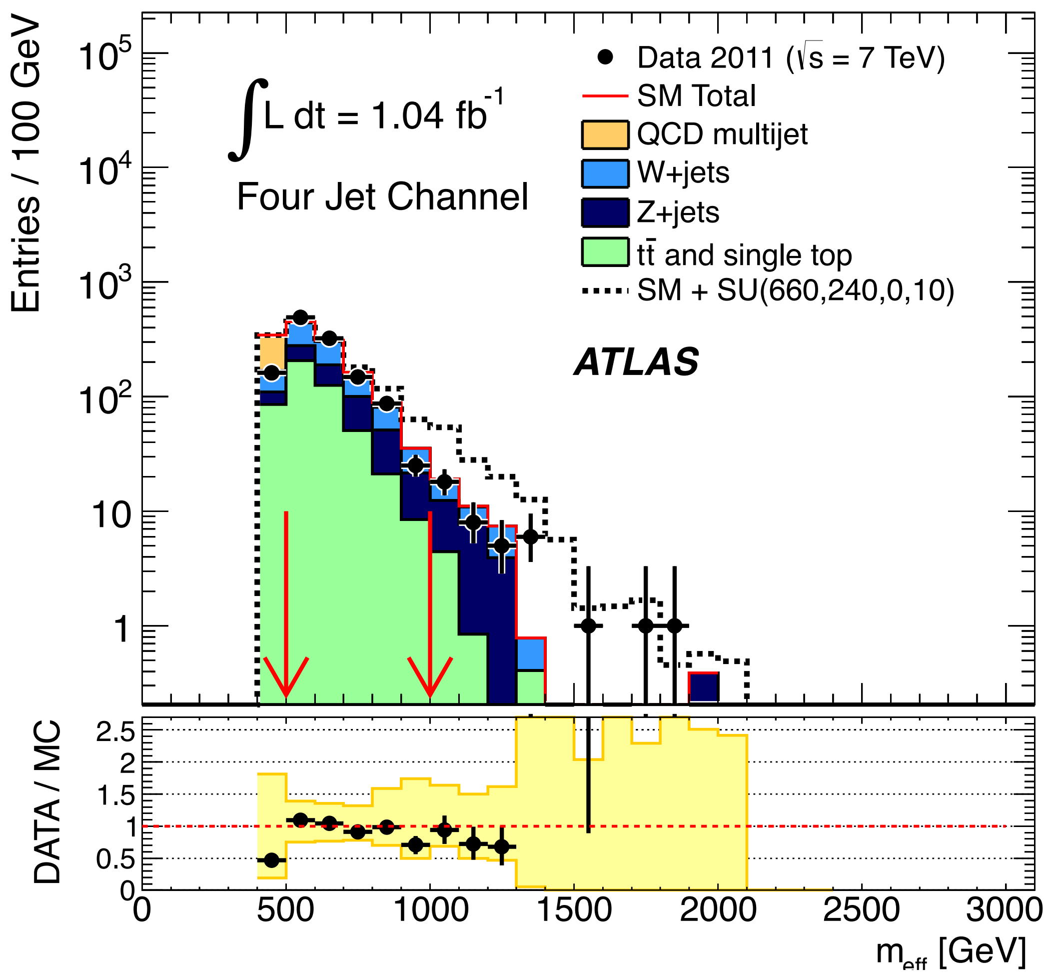
		$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{g}\tilde{g}$	$\tilde{g}\tilde{g}$
	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130	> 130	> 130	> 130
Trigger	Leading jet p_{T}	> 130	> 130	> 130	> 130
Jet multiplicity	Second jet p_{T}	> 40	> 40	> 40	> 80
Jet multiplicity	Third jet p_{T}	–	> 40	> 40	> 80
Jet multiplicity	Fourth jet p_{T}	–	–	> 40	> 80
QCD rejection	$\Delta\phi(\text{jet}, E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
QCD rejection	$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
Signal region def →	m_{eff} [GeV]	> 1000	> 1000	$> 500/1000$	> 1100

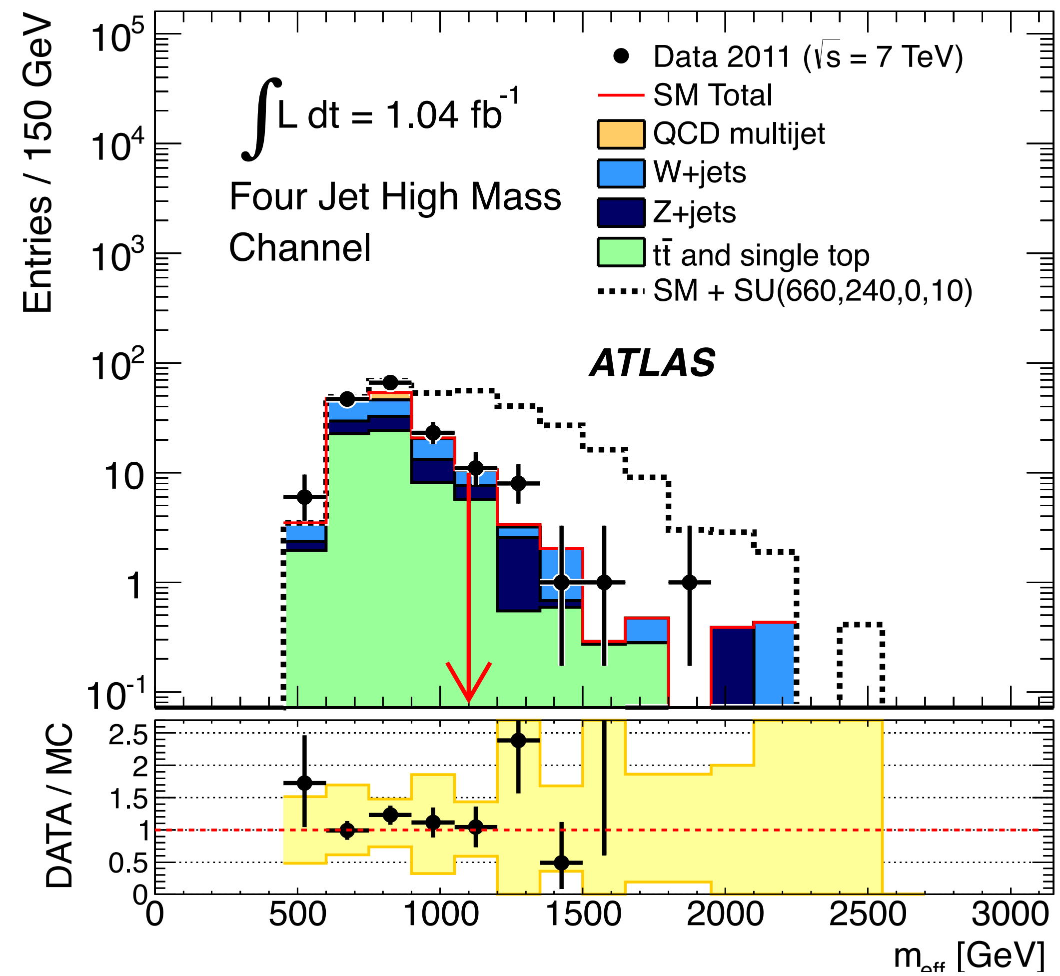
$$E_T^{miss} + \sum_{SRjets} p_T \quad \Big| \quad E_T^{miss} + \sum_{p_T > 40} p_T$$

- All backgrounds (QCD, Z, W, top) are estimated from their corresponding Control Region
- QCD determination is fully data-driven
- Other backgrounds use MC for extrapolation

Results

arXiv:1109.6572



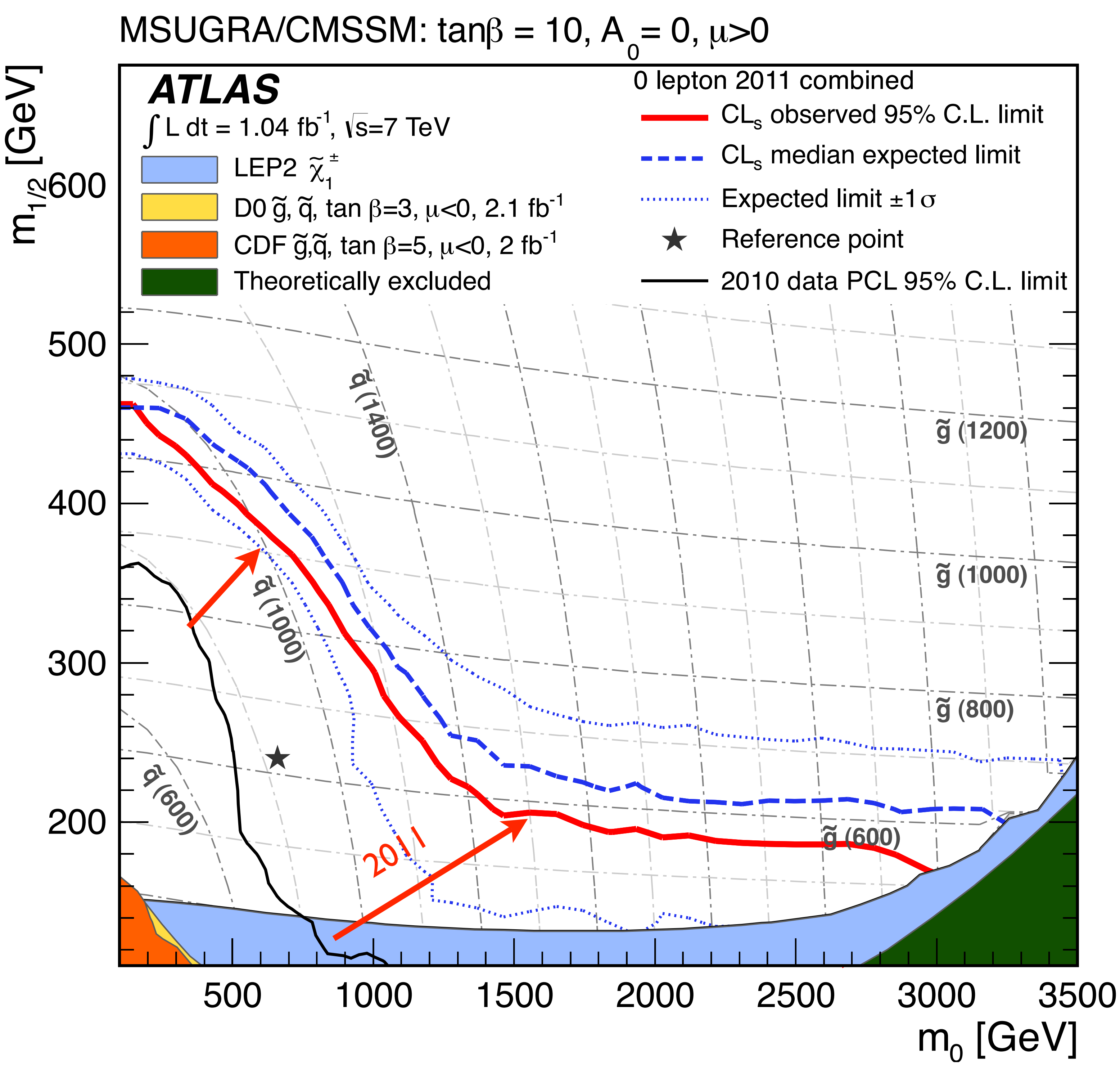


Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff}$ > 500 GeV	$\geq$ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Total SM	$62.3 \pm 4.3 \pm 9.2$	$55 \pm 3.8 \pm 7.3$	$984 \pm 39 \pm 145$	$33.4 \pm 2.9 \pm 6.3$	$13.2 \pm 1.9 \pm 2.6$
Data	58	59	1118	40	18

- Good agreement between SR observations and SM prediction

Interpretation

arXiv:1109.6572



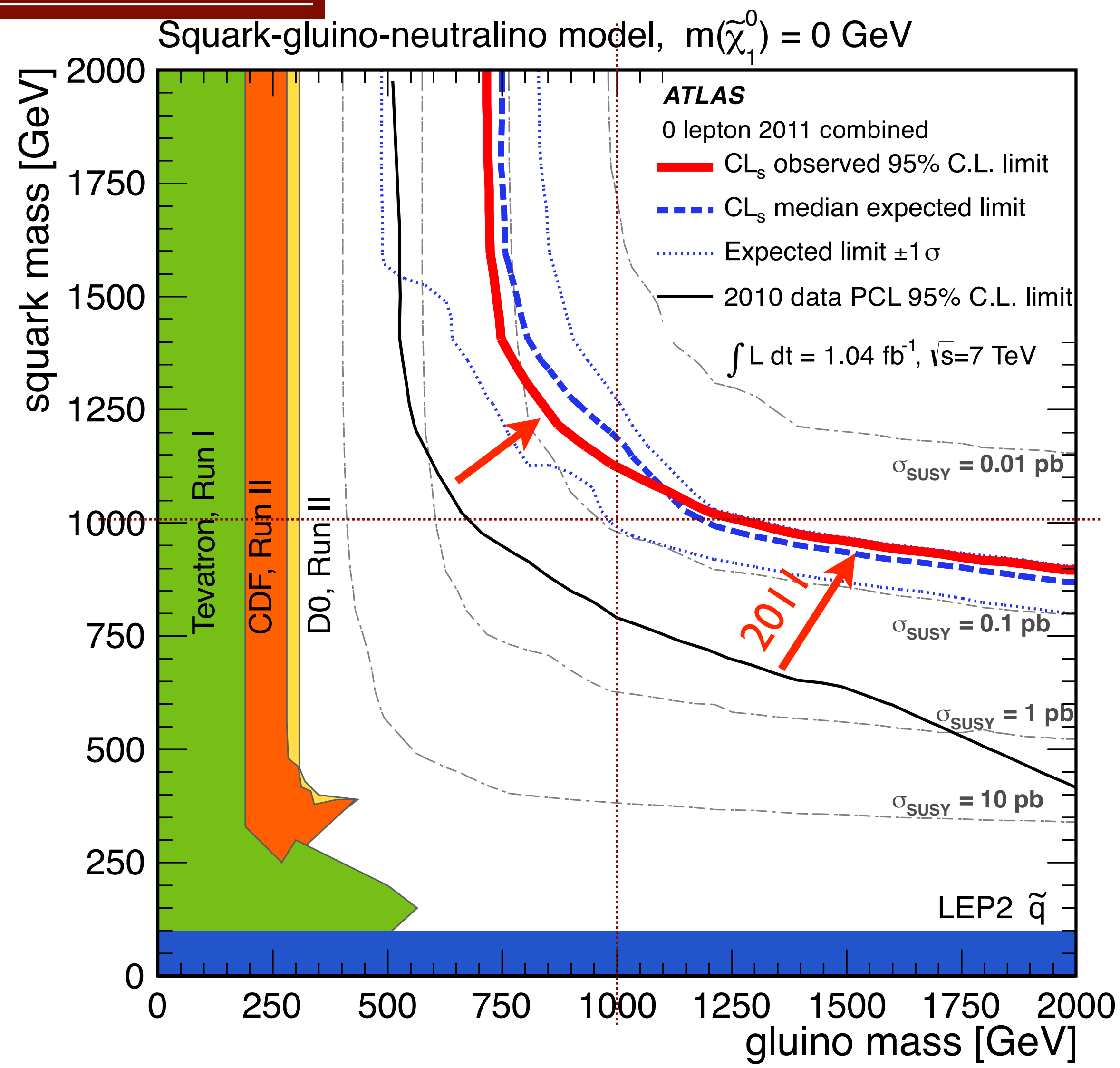
CMSSM/mSUGRA

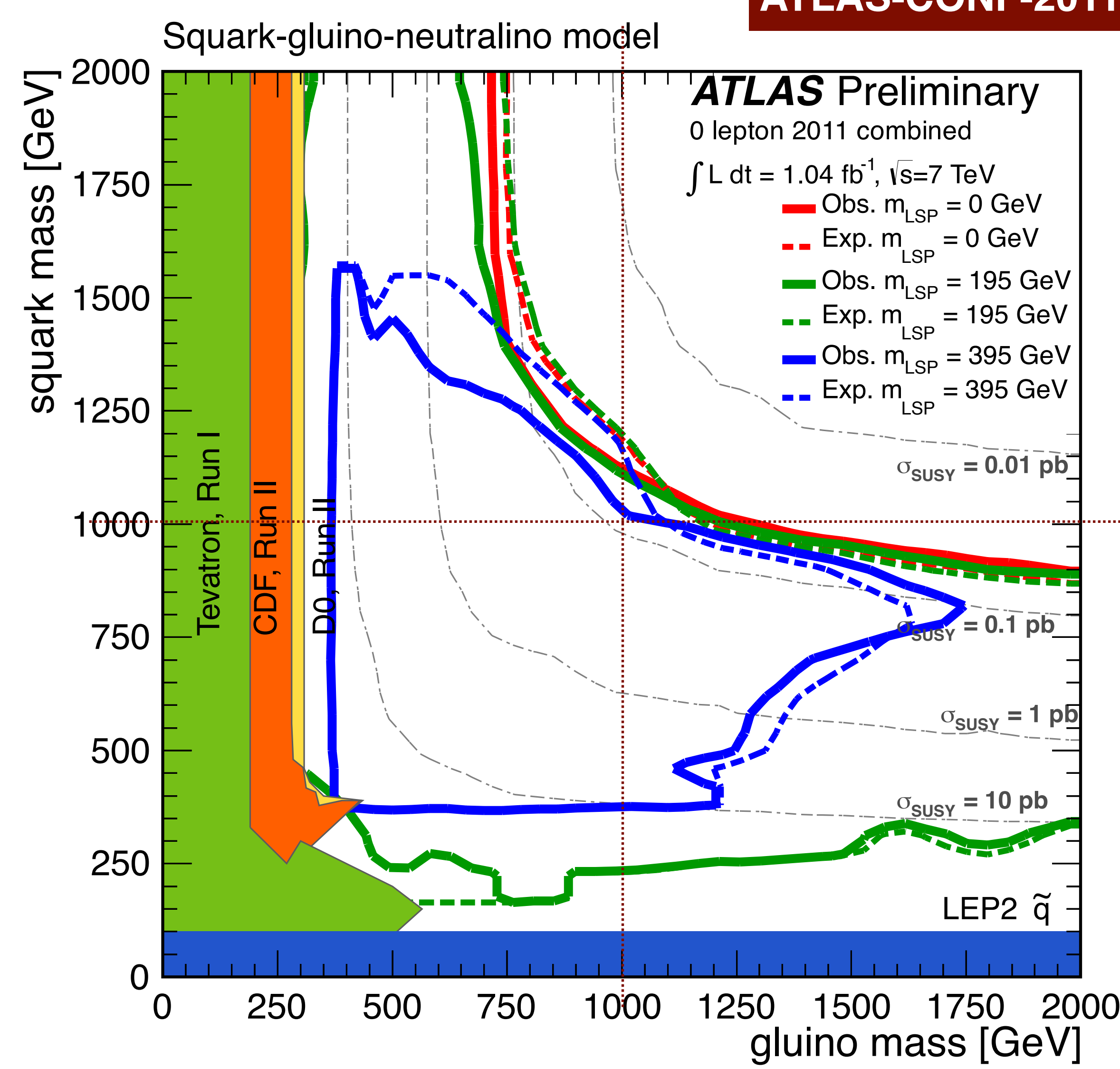
- $L=1.04\ fb^{-1}$
- $A_0=0$, $\mu>0$, $\tan\beta=10$
- Combined: SR with best expected limit
- Exclusion:
  - $m_{1/2}\sim 450$ GeV for low m_0
  - $m_{1/2}>200$ GeV for all m_0
  - $m_{sq}, m_{gl} > 950$ GeV for equal mass
- New Signal Regions extend the reach into high m_0

Simplified model

arXiv:1109.6572

ATLAS-CONF-2011-155





- Only 3 SUSY particles:
  - squarks (mass-degenerate)
  - gluinos
  - LSP (m=0)
  - Other sparticles decoupled
- Exclusion up to m ~ 1TeV !

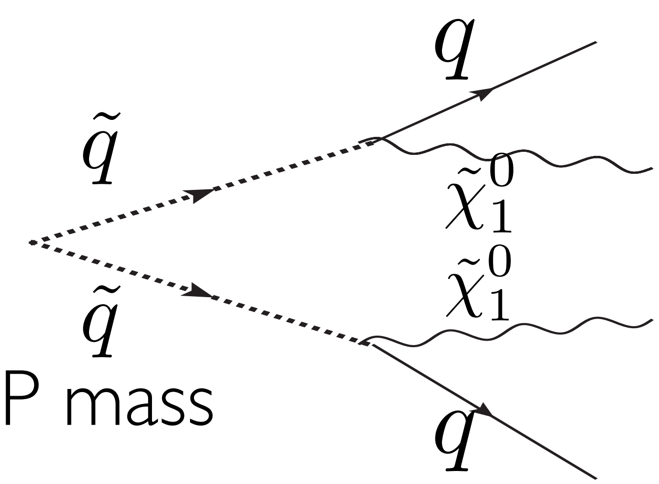
- What about limits for non-zero LSP?
  - LSP (m=**0**, **195**, **395** GeV)
- Exclusion does not change up to m_{LSP}~200 GeV
- Limit worsens for m_{LSP} =400 GeV

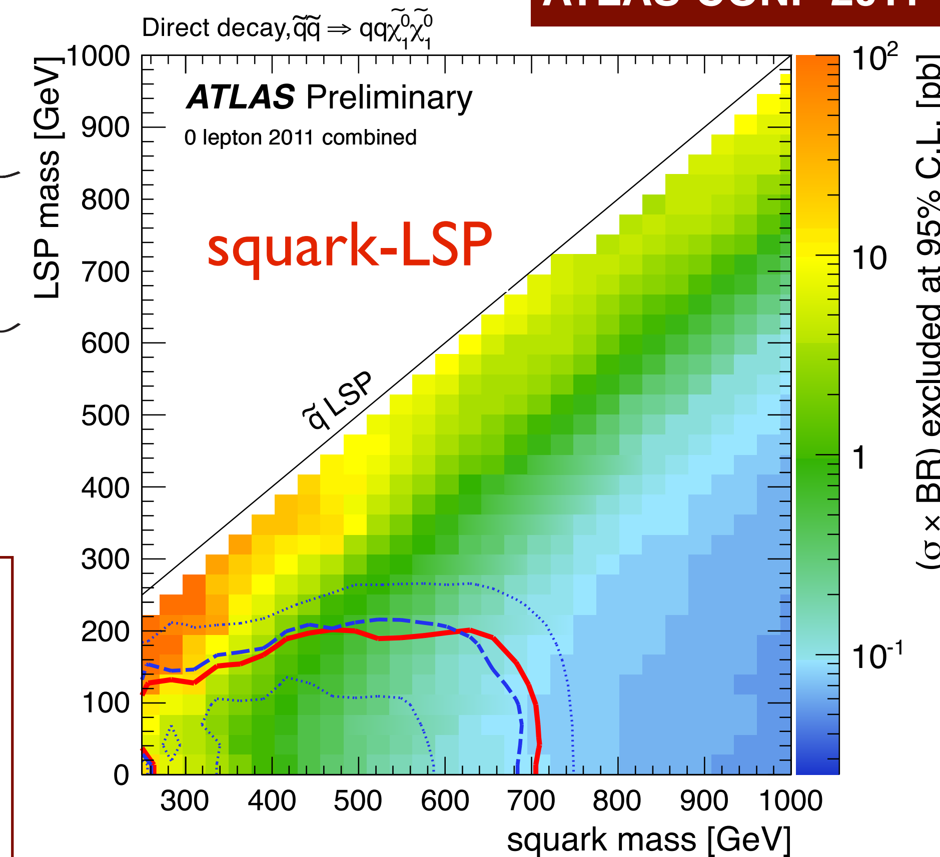
Additional interpretation

ATLAS-CONF-2011-155

Direct squark decay:

Free parameters: squark and LSP mass



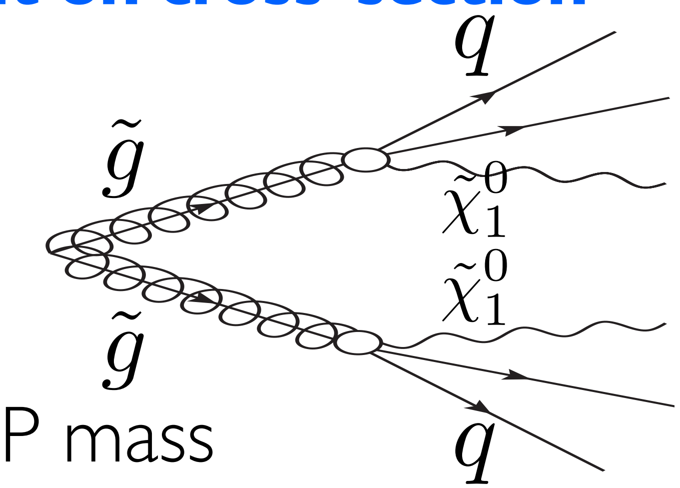


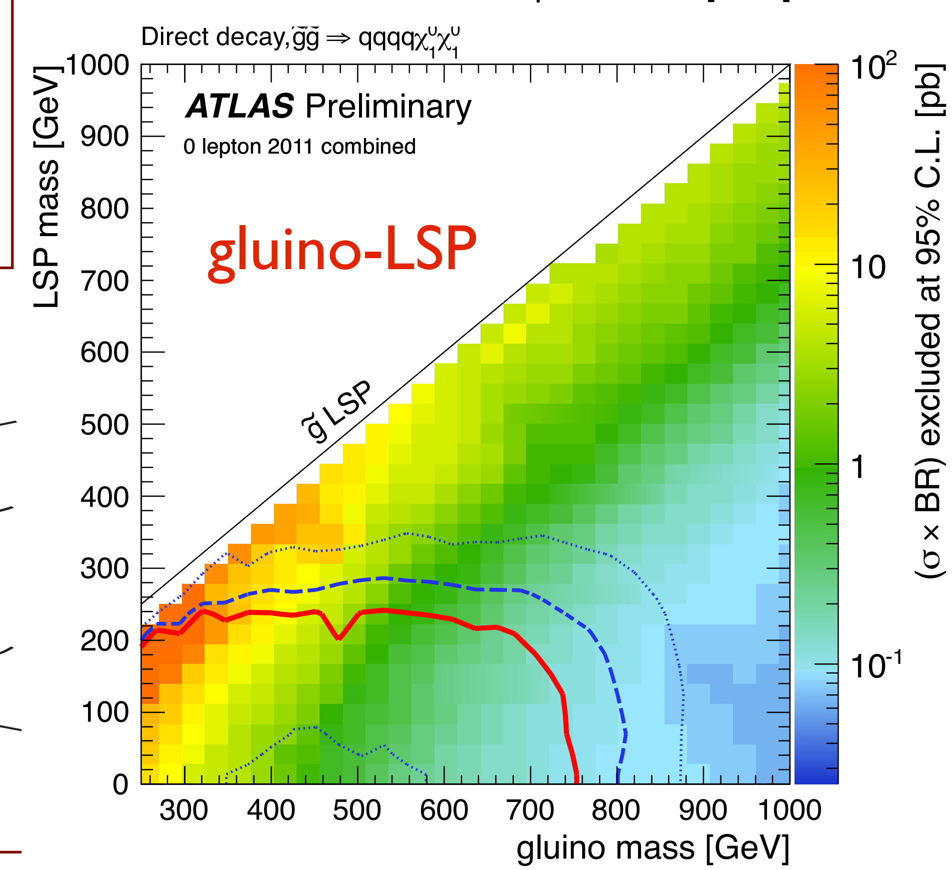
- Limits on squark/gluino mass do not hold for heavy LSP!
- Depends on mass-splitting
  - ➡ softer spectra (jets, E_T^{miss})
- Have many other interpretations, e.g. UED

Colour-coding gives upper-limit on cross-section

Direct gluino decay:

Free parameters: gluino and LSP mass

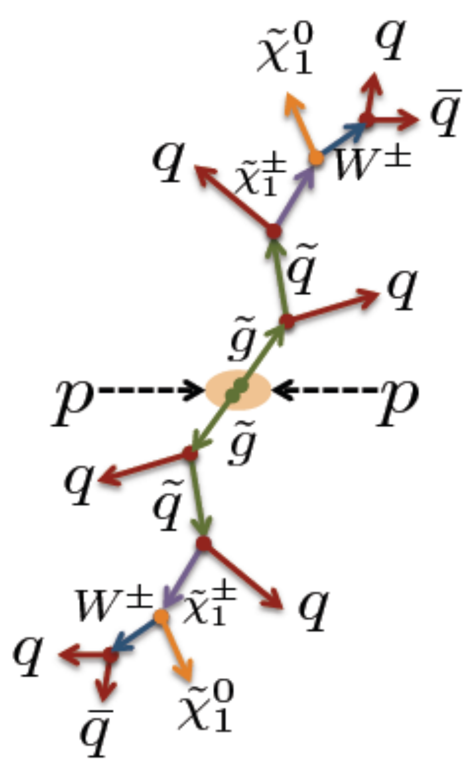




Multijets
(L=1.34fb^{-1})

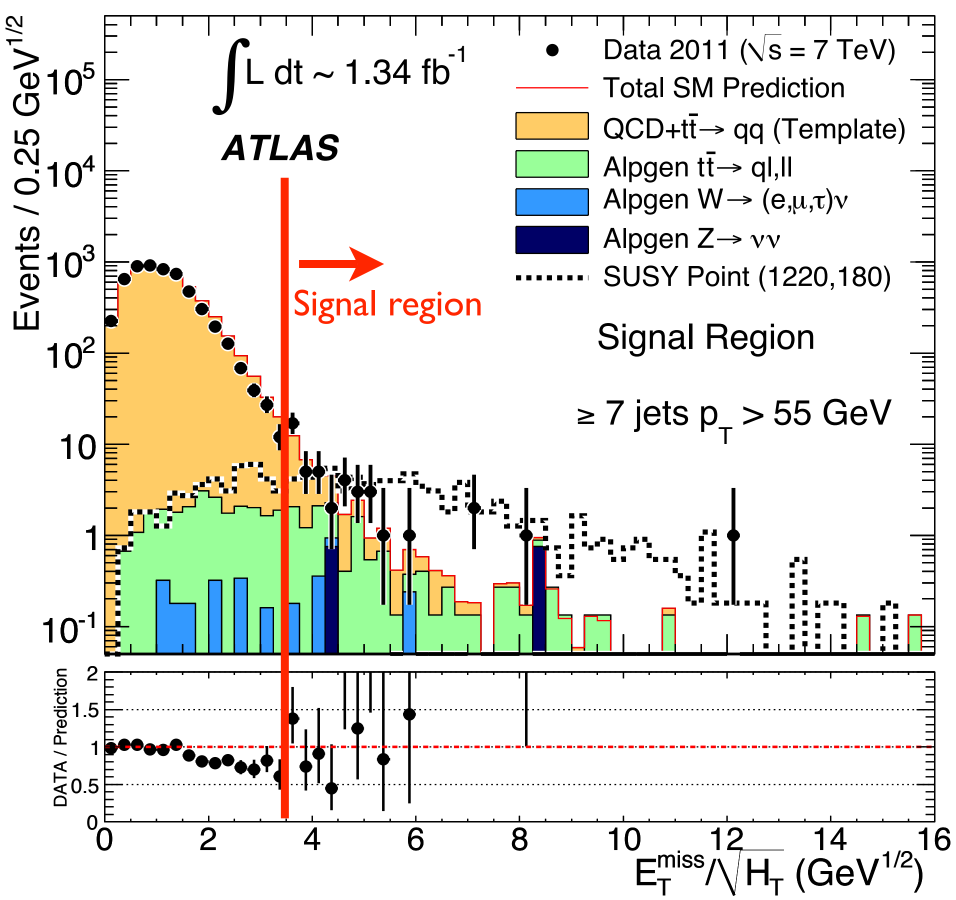
Outline of analysis

JHEP11(2011)099



- Extension of jets+E_T^{miss} analysis
- Search for long decay chains without leptons → many jets!
  - E.g. multi-step gluino decays, high m_0
- Discriminating variable: $E_T^{miss}/\sqrt{\sum p_T}$
- Multijet triggers allow much lower E_T^{miss}

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
$E_T^{miss}/\sqrt{H_T}$	> 3.5 GeV$^{1/2}$			



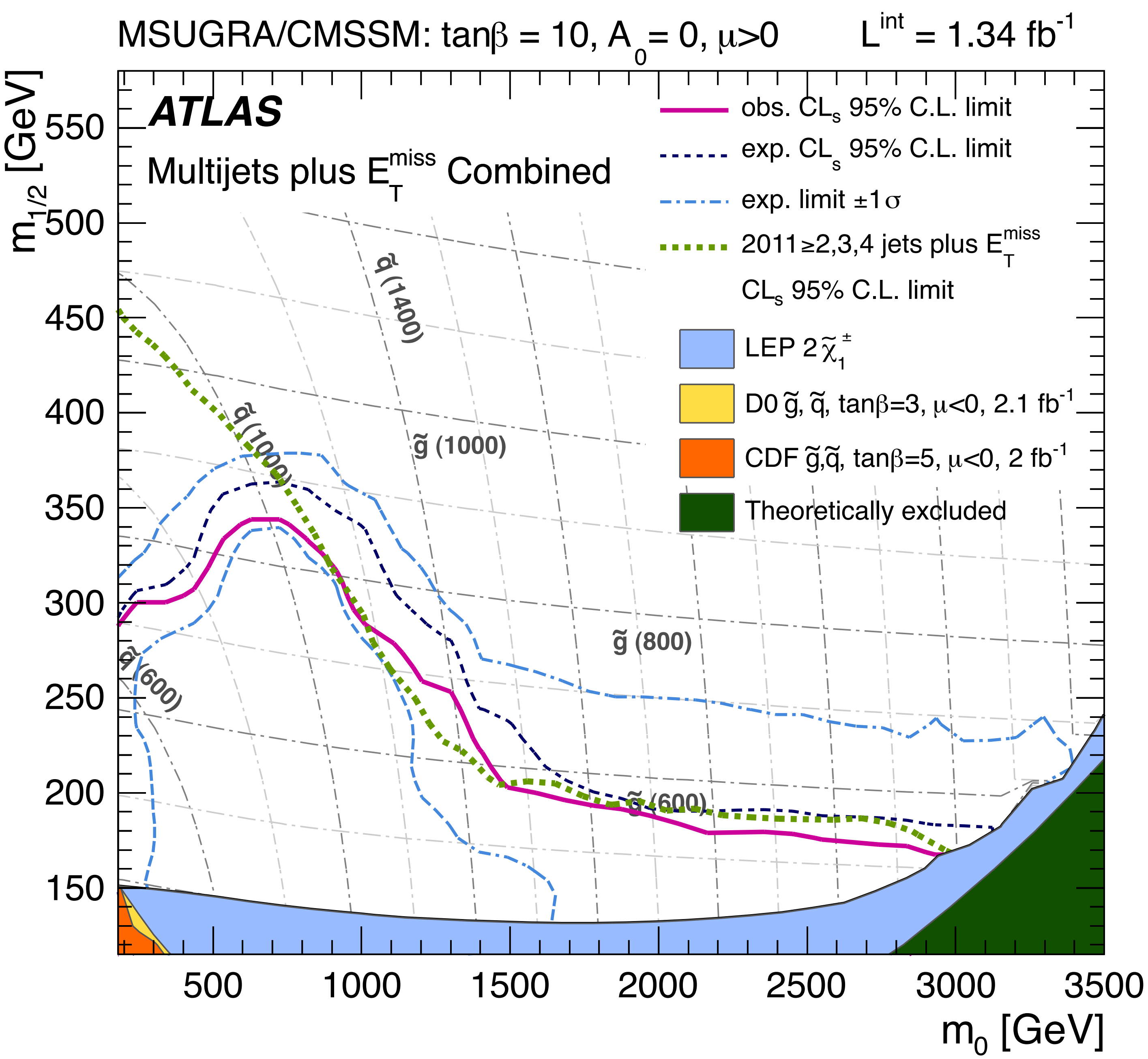
Background:

- $E_T^{miss}/\sqrt{\sum p_T}$ is independent of number of jets
- For QCD: estimate in lower N_{jet} bins
- Top: like 2-4 jets - W/Z+jets from simulation

Results & interpretation

JHEP11(2011)099

Signal region	7j55	8j55	6j80	7j80
Total SM	$39.3^{+8.7}_{-8.5}$	$2.3^{+4.4}_{-0.7}$	25.8 ± 6.1	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3



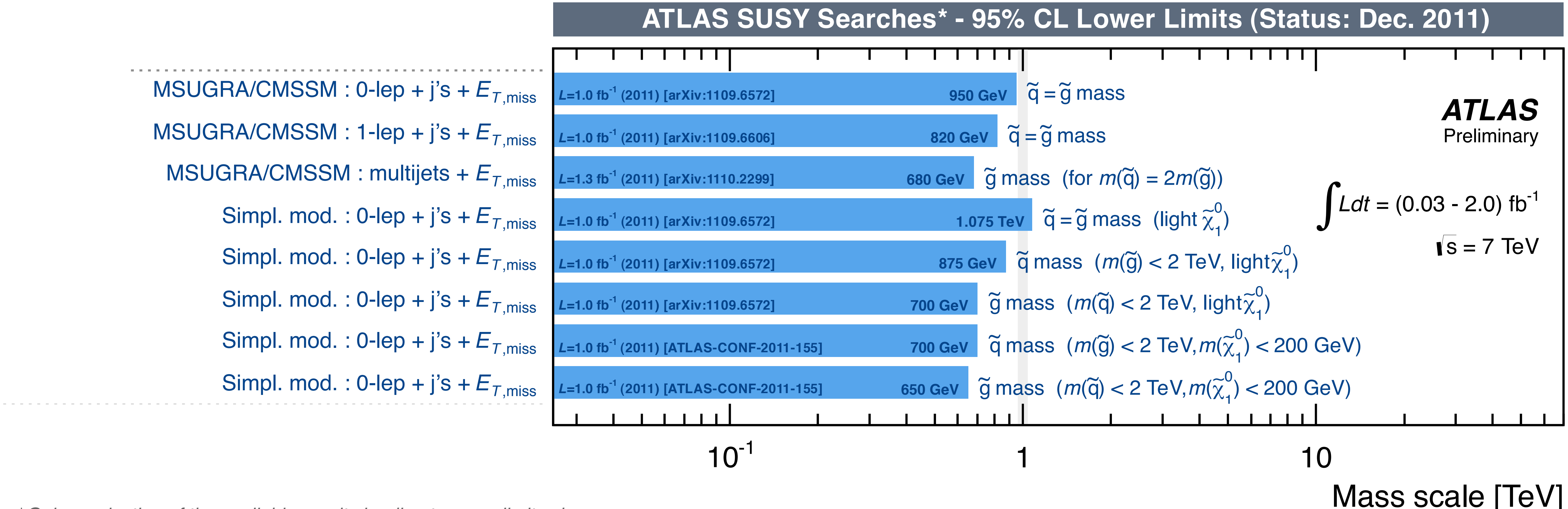
- Analysis extends previous limit slightly
  - Gluino mass > 520 GeV
  - If m_{sq}=2 m_{gl}: gluino mass > 680 GeV

Conclusions

- The first fb^{-1} ATLAS data has given us no signs of SUSY
- But using jets + missing energy analyses we have drastically improved the limits on SUSY models
  - on CMSSM:
    - $m_{1/2}$~450 GeV for low m_0
    - $m_{1/2}$>200 GeV for all m_0
  - on simplified MSSM models: exclusion up to m ~ 1 TeV
- Limits fall short for some models, e.g. lower mass-splitting models: start a dedicated search!
- Updates will come shortly (next weeks)
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- And of course a big thanks to both LHC and ATLAS operations!

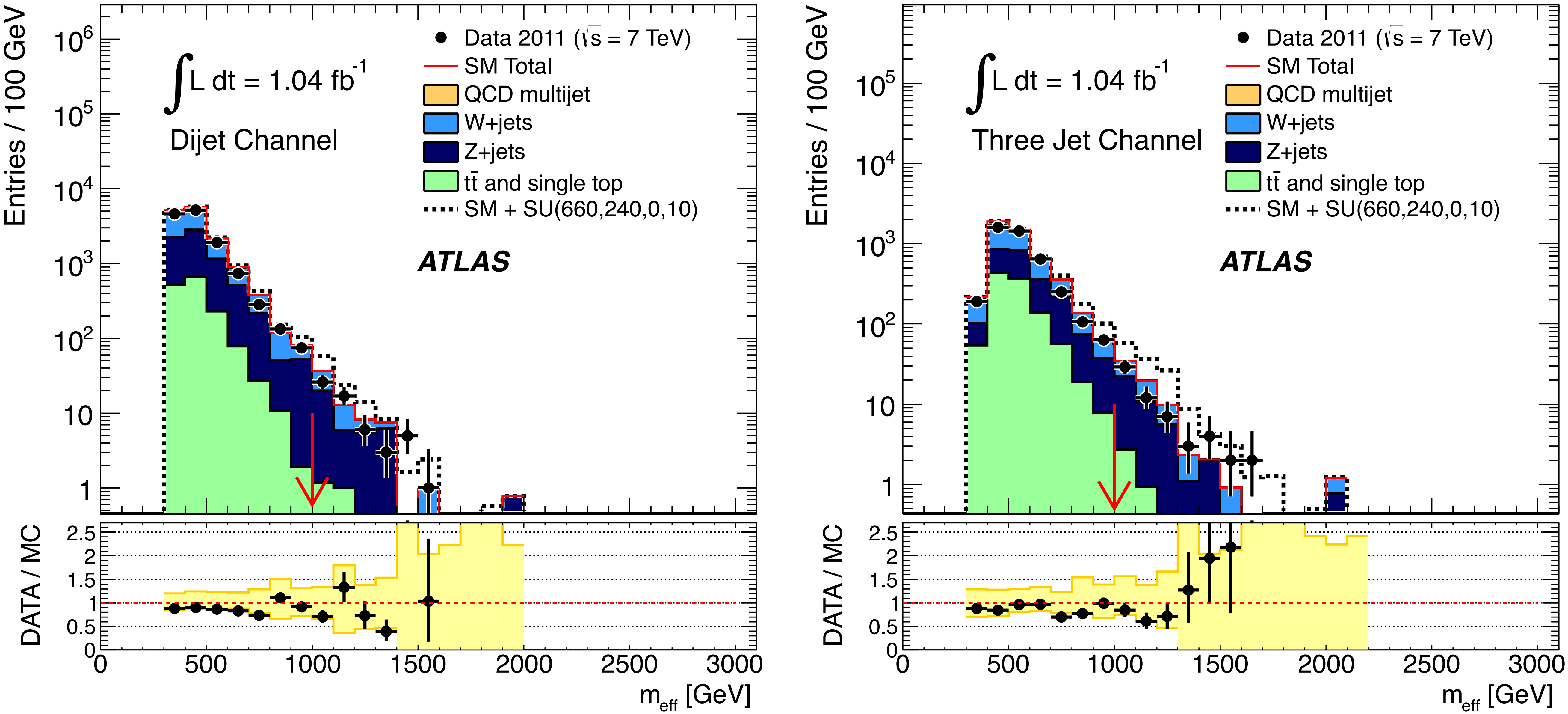
Backup

Summary plot



*Only a selection of the available results leading to mass limits shown

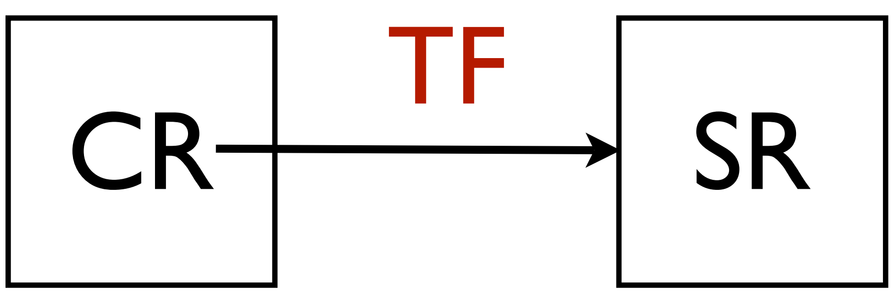
Signal regions 2,3 jets



- **SRA** (left) and **SRB** (right) before m_{eff} cuts
- Histograms: MC background expectations, normalised to lumi (except QCD)
  - QCD estimated using data-driven jet smearing technique
- Yellow band denotes combined JES, JER and statistical uncertainties
- The CMSSM point shown lies just beyond the reach of the previous analysis

Transfer Factors

- Observed event counts in the CRs for each channel are used to generate normalized SM background estimates for SR
  - This way: CR contamination by other SM processes and/or SUSY signal events taken into account.
- Transfer Factors (TF) enable observations in the CRs to be converted into background estimates in the SR:



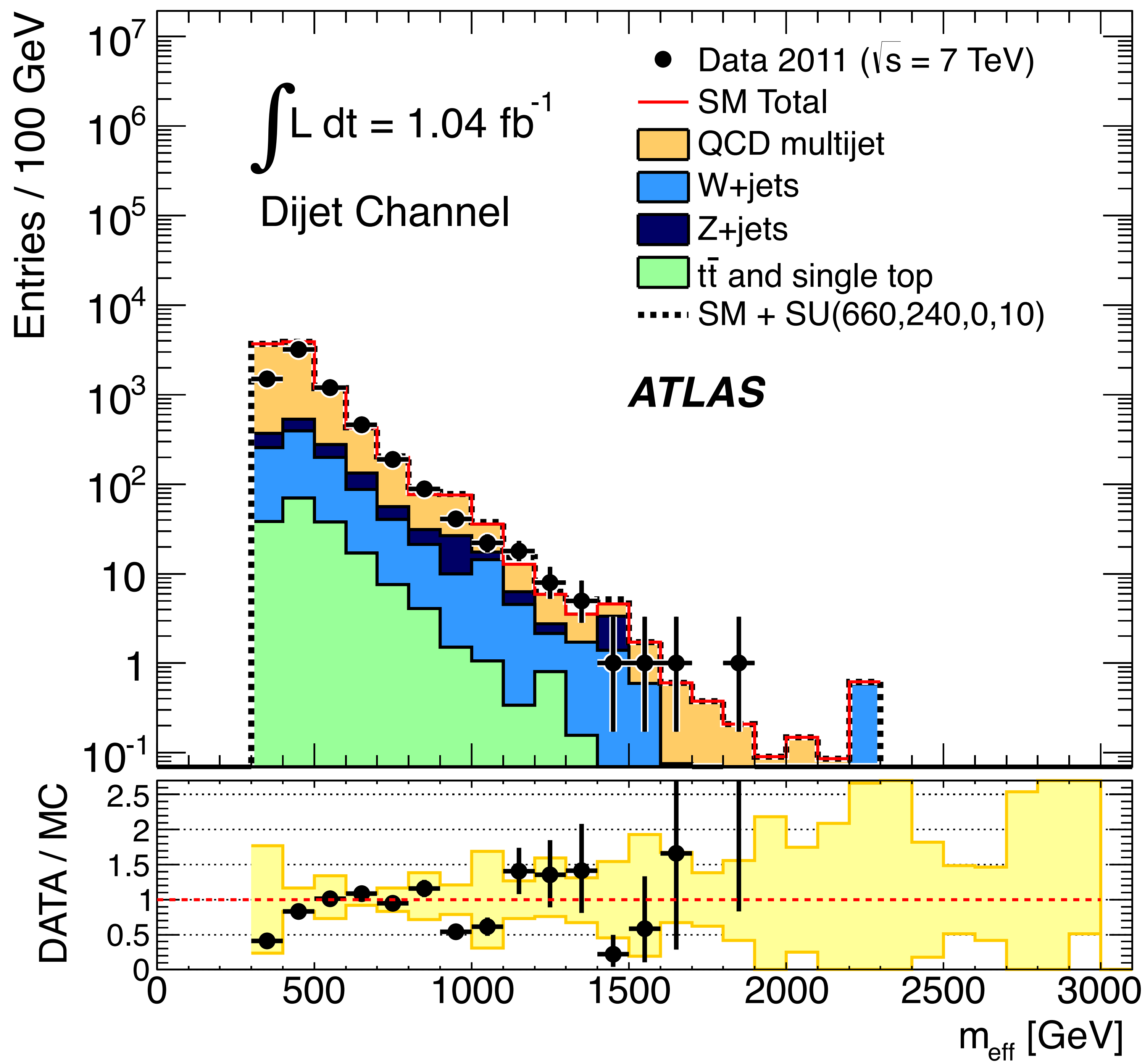
TF

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

- CR2 (QCD): TFs are estimated using data-driven technique
- Other CRs: TFs are estimated using data-validated fully simulated Monte Carlo (MC) event samples (semi-data driven estimation)

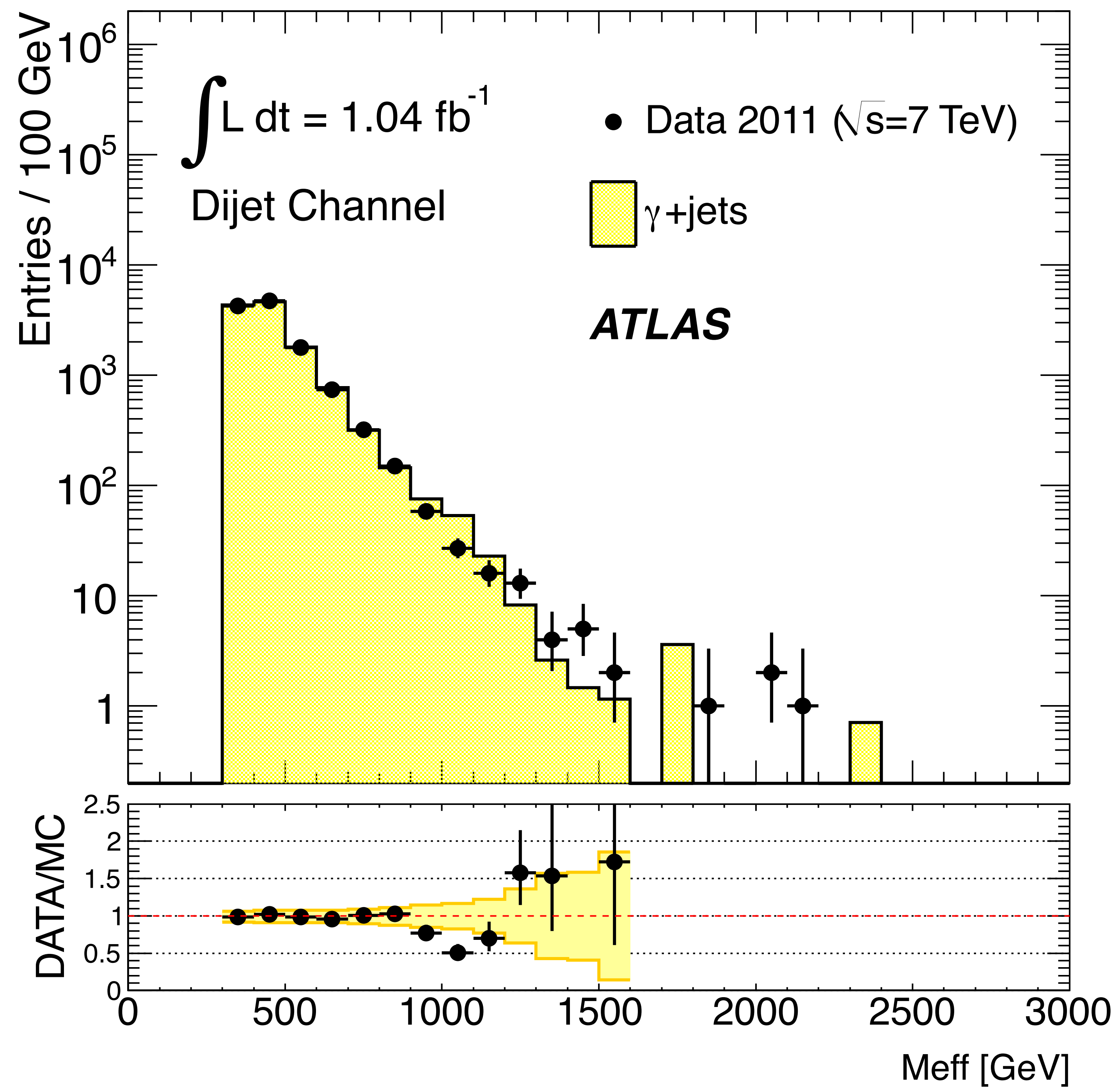
QCD estimation

- Data-driven technique: convolve *jet response* function with seed events to get estimate at high m_{eff}
    - Seed events from low E_T^{miss} multijet events
- Results in **ΔΦ** distribution at high m_{eff} - use this as input for CR2 to get Transfer Factor
- Validate using semi-data-driven technique



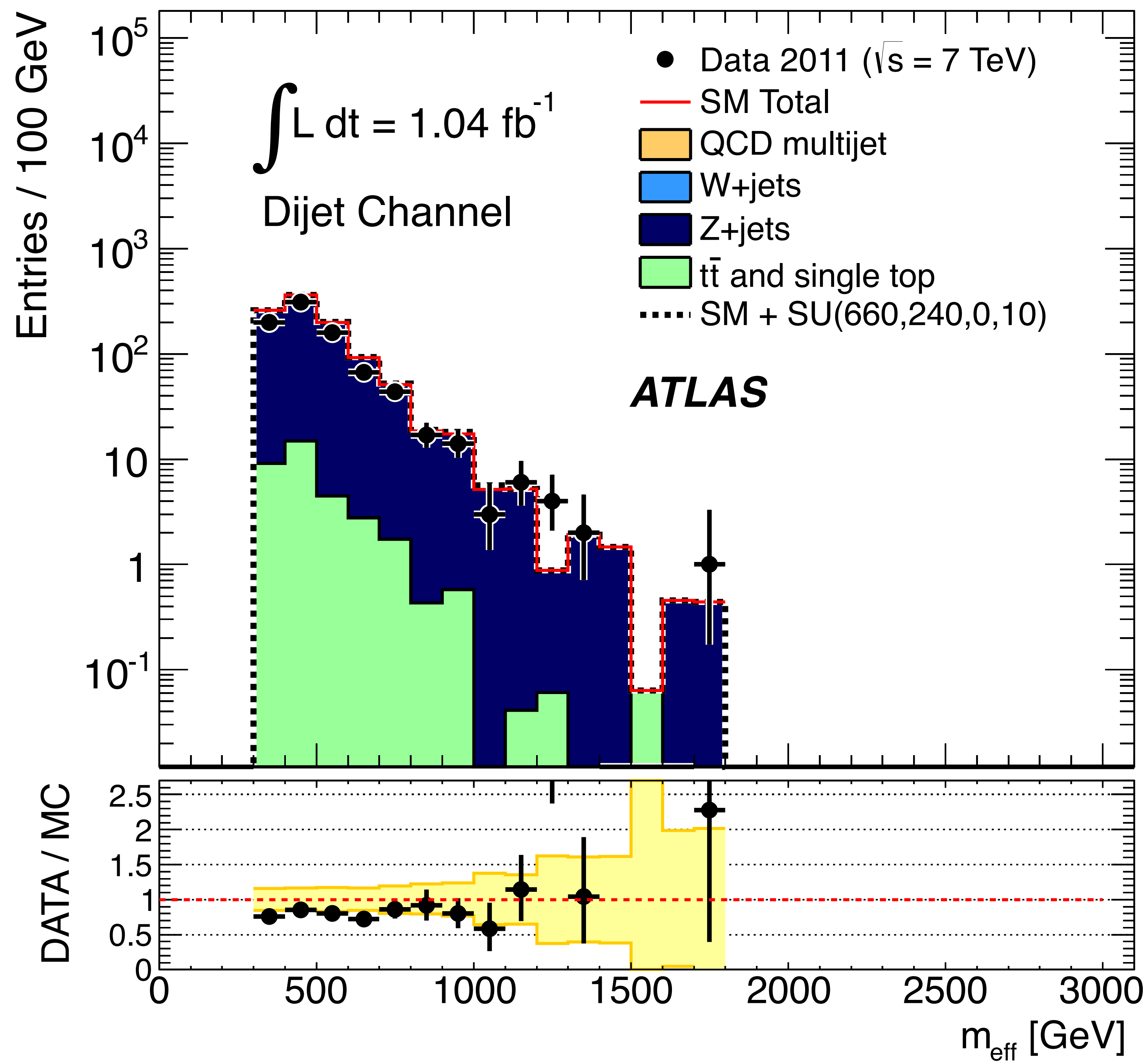
2-4 jets: Examples of CRs

- For Z+jets there are two CRs:
  - **γ+jets with photon treated as jet**
  - Z(→ll)+jets with Z treated as jet
- As example: ≥2jet channel



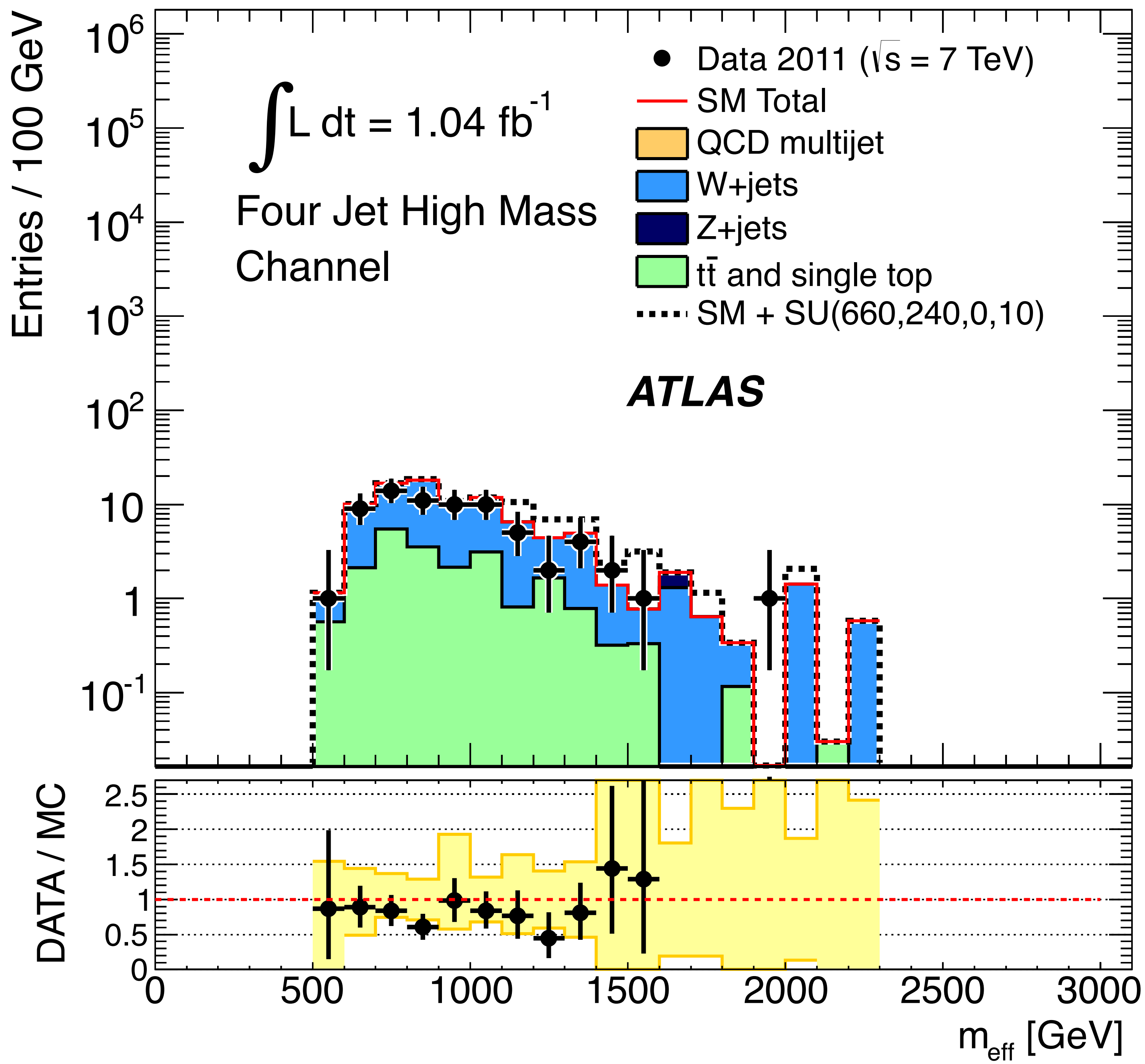
2-4 jets: Examples of CRs

- For Z+jets there are two CRs:
  - γ+jets with photon treated as jet
  - **Z(→ll)+jets with Z treated as jet**
    - 2 leptons selected
- As example: ≥2jet channel



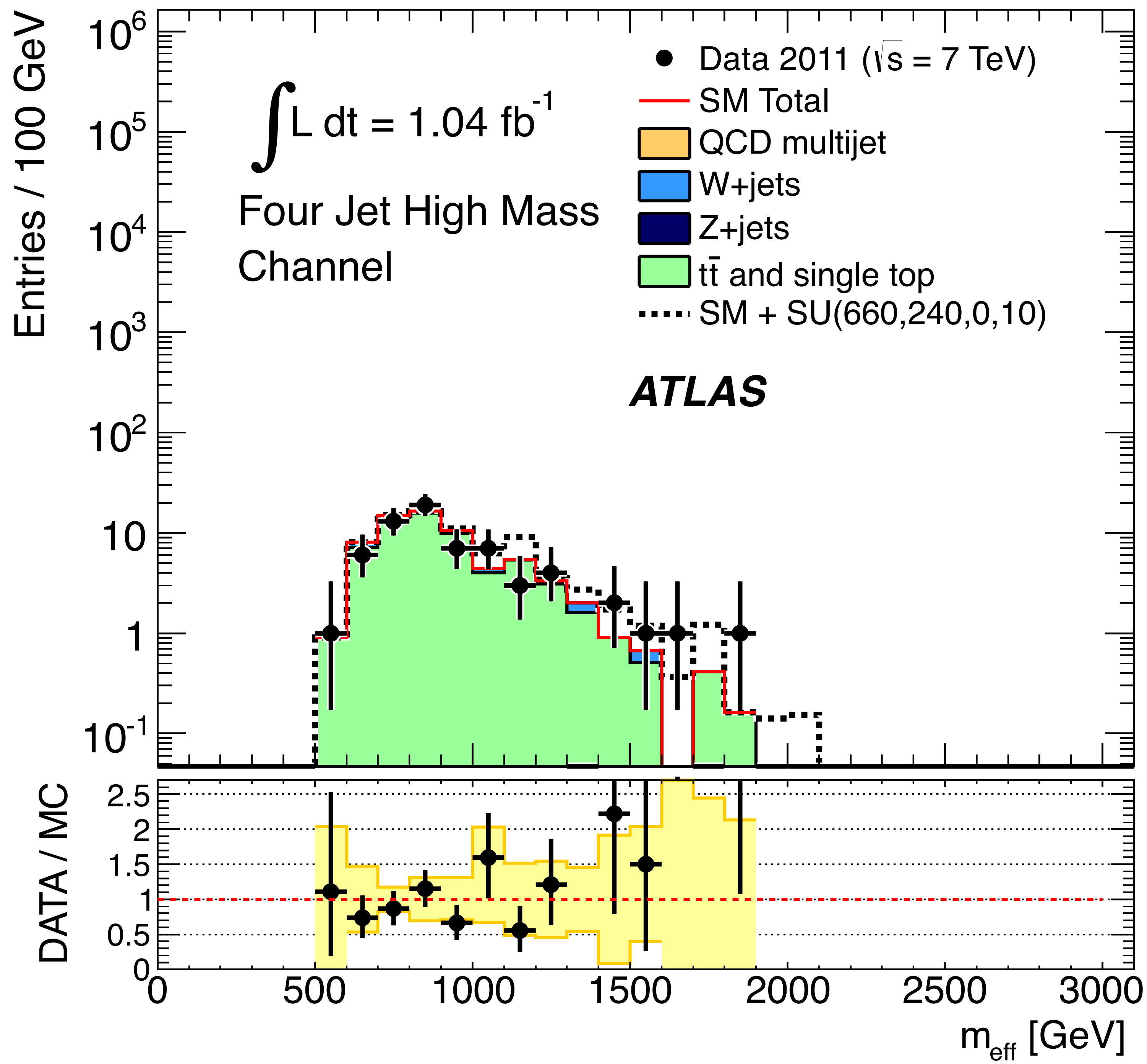
2-4 jets: Examples of CRs

- **W+jets CR:**
  - Select 1 lepton
  - Require $30 > m_T(l, E_T^{miss}) > 100$
  - b-jet **veto**
- As example: CR W for ≥4jet highmass



2-4 jets: Examples of CRs

- **Top CR:**
    - Select 1 lepton
    - Require $30 > m_T(l, E_T^{miss}) > 100$
    - b-jet **tag**
- As example: CR Top for ≥4jet highmass



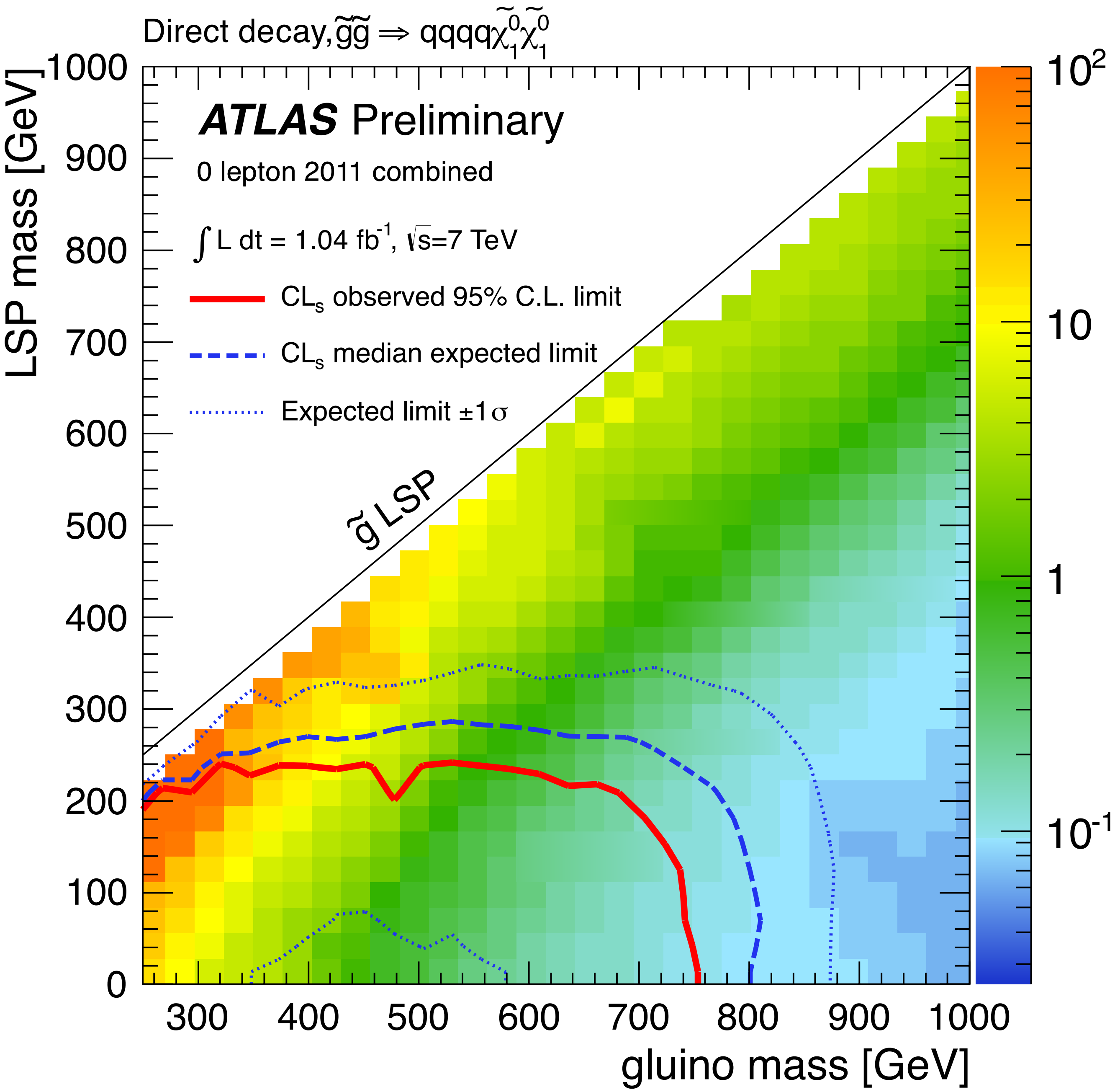
Full Results 2-4 jets

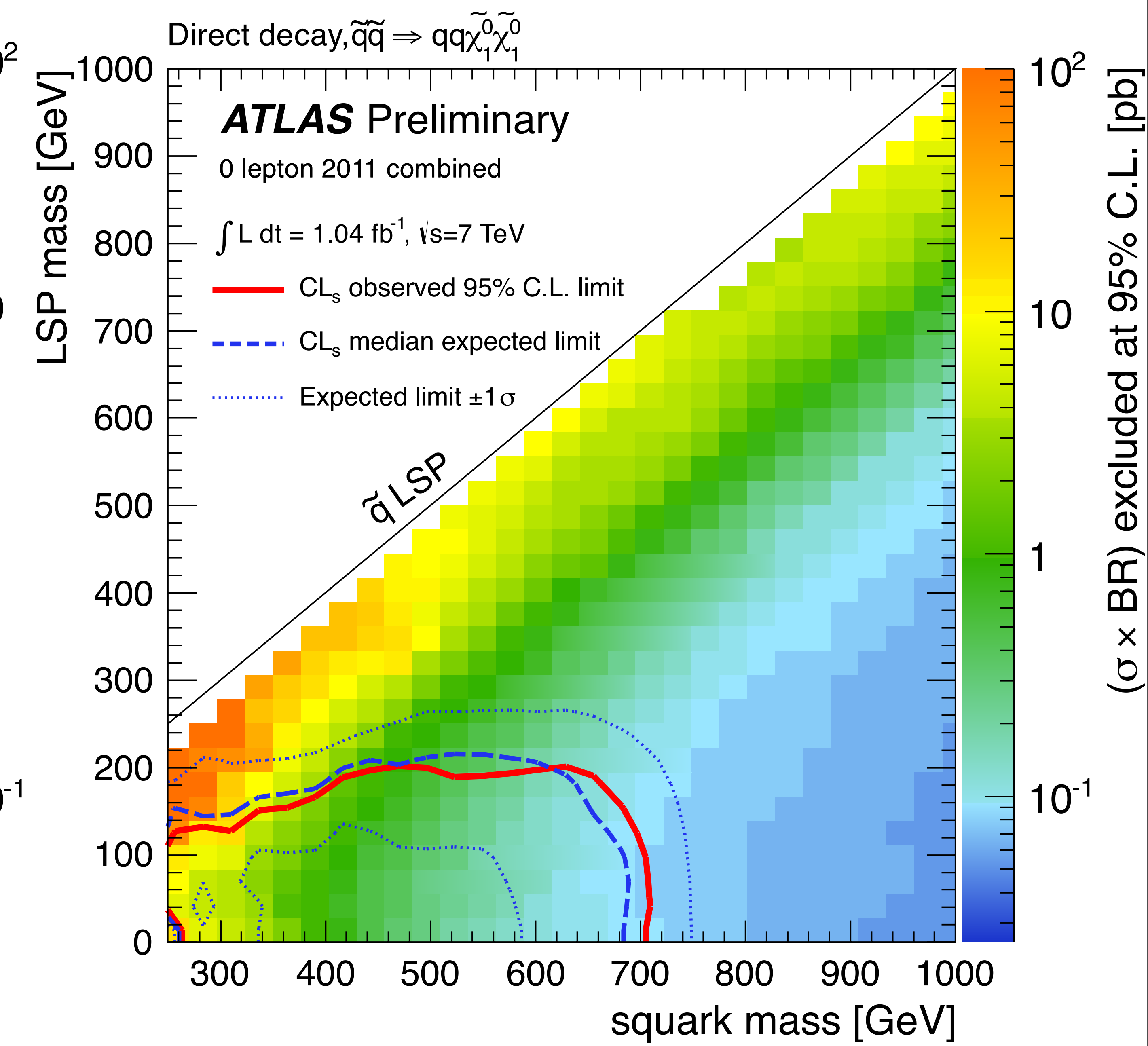
Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\text{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 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

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\text{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Excluded $\sigma\times$ Acc $\times\varepsilon$ (fb)	24	30	477	32	17

Additional interpretation

Larger plots



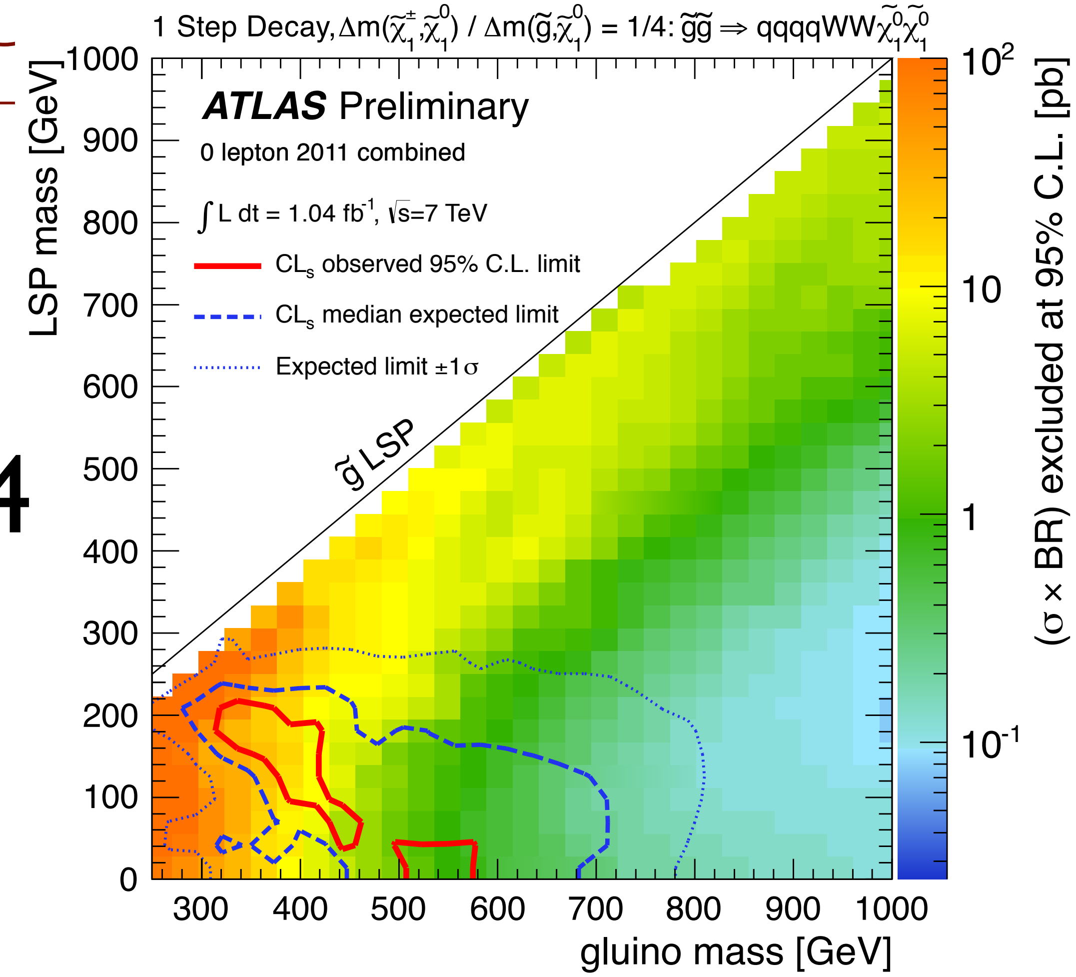


Add. interpr.: 1 step decay

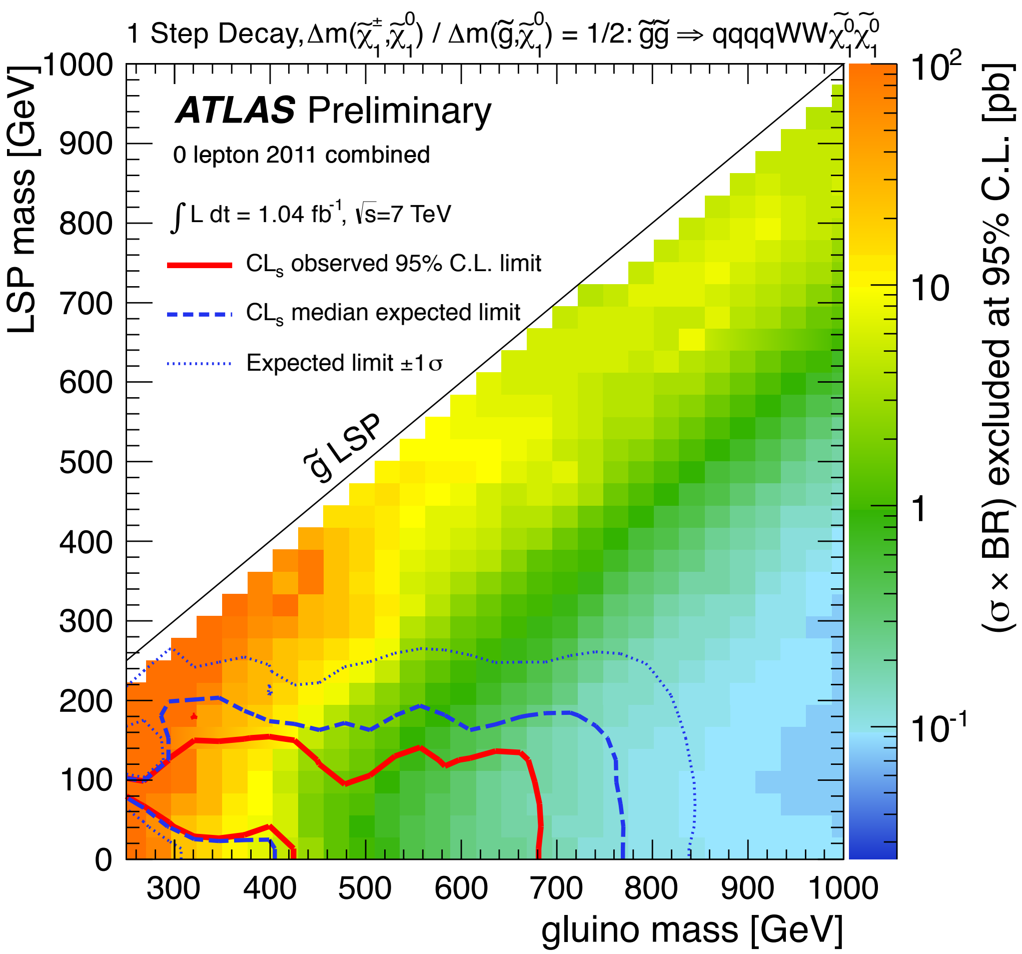
- For Simplified models with a one-step gluino decay:
$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^{\pm} \rightarrow q\bar{q}W\tilde{\chi}_1^0$
with chargino mass related to gluino and LSP by:

$$x = \frac{m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{q}_L,\tilde{g}} - m_{\tilde{\chi}_1^0}}$$

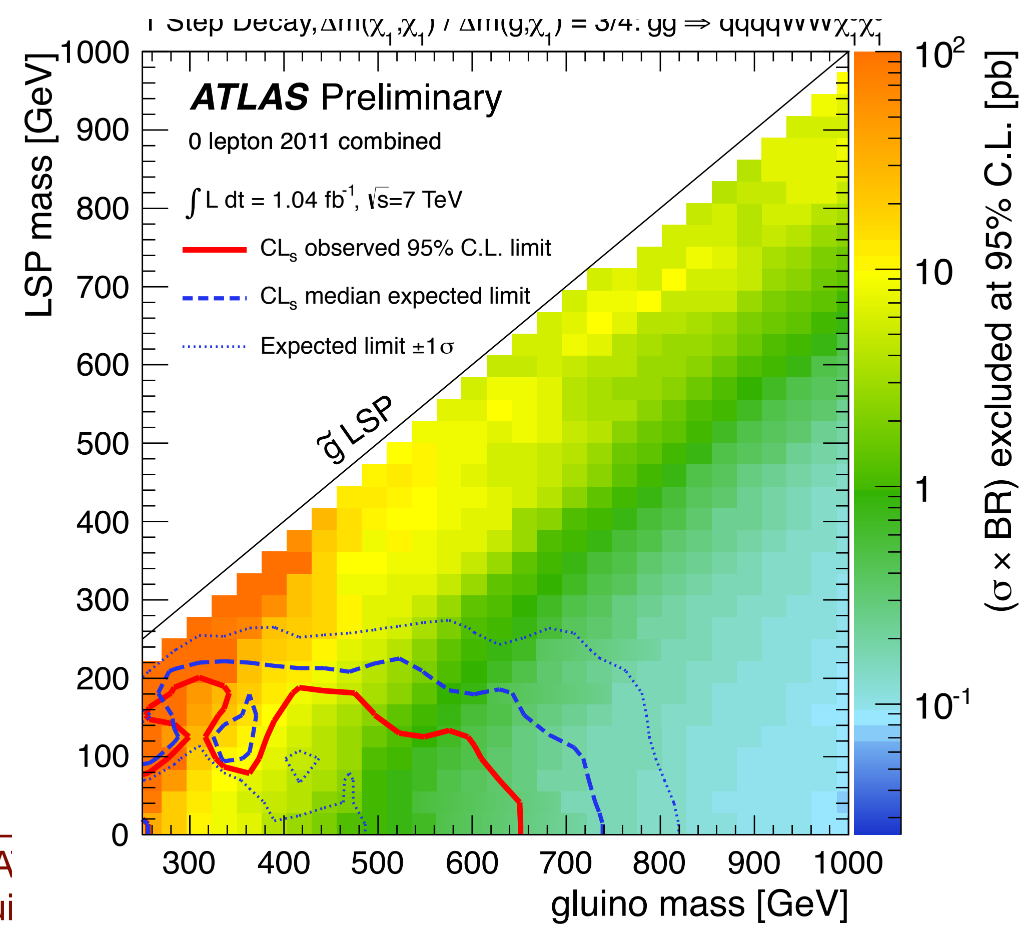
x=1/4



x=1/2



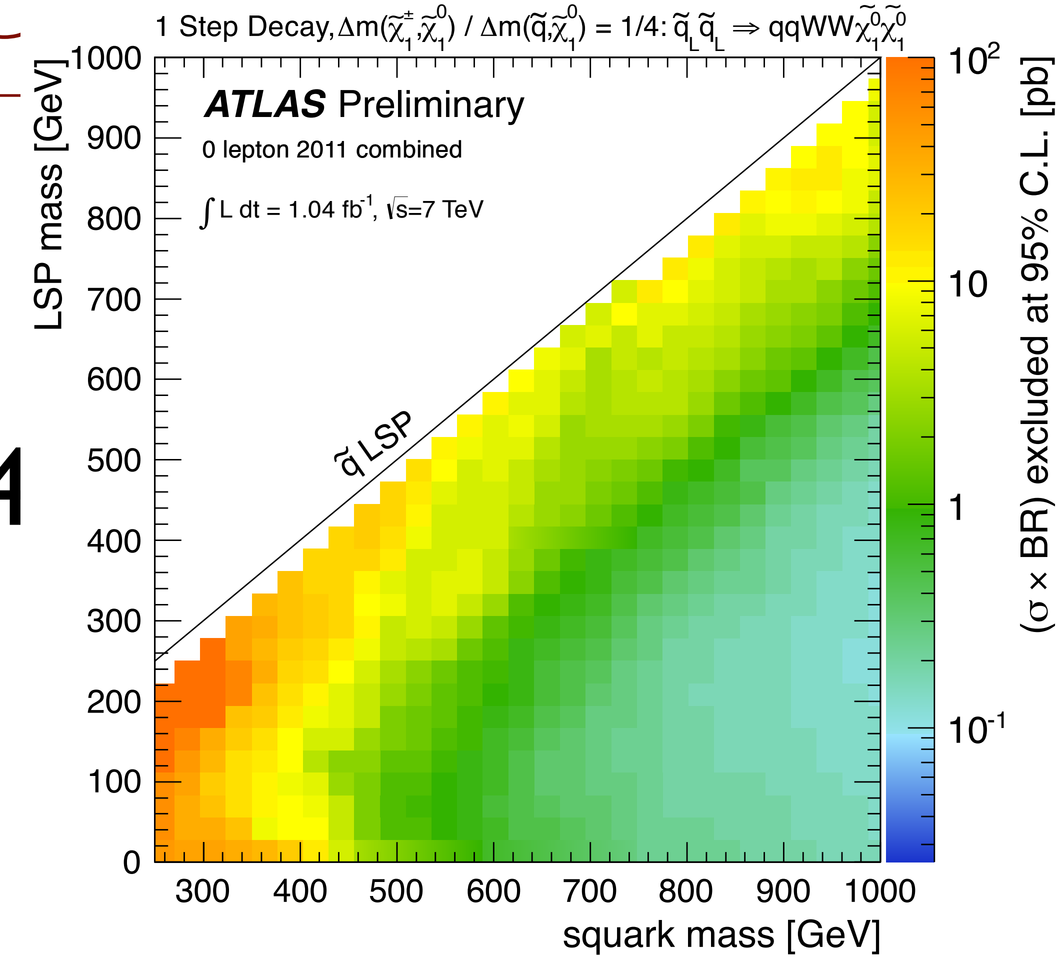
x=3/4



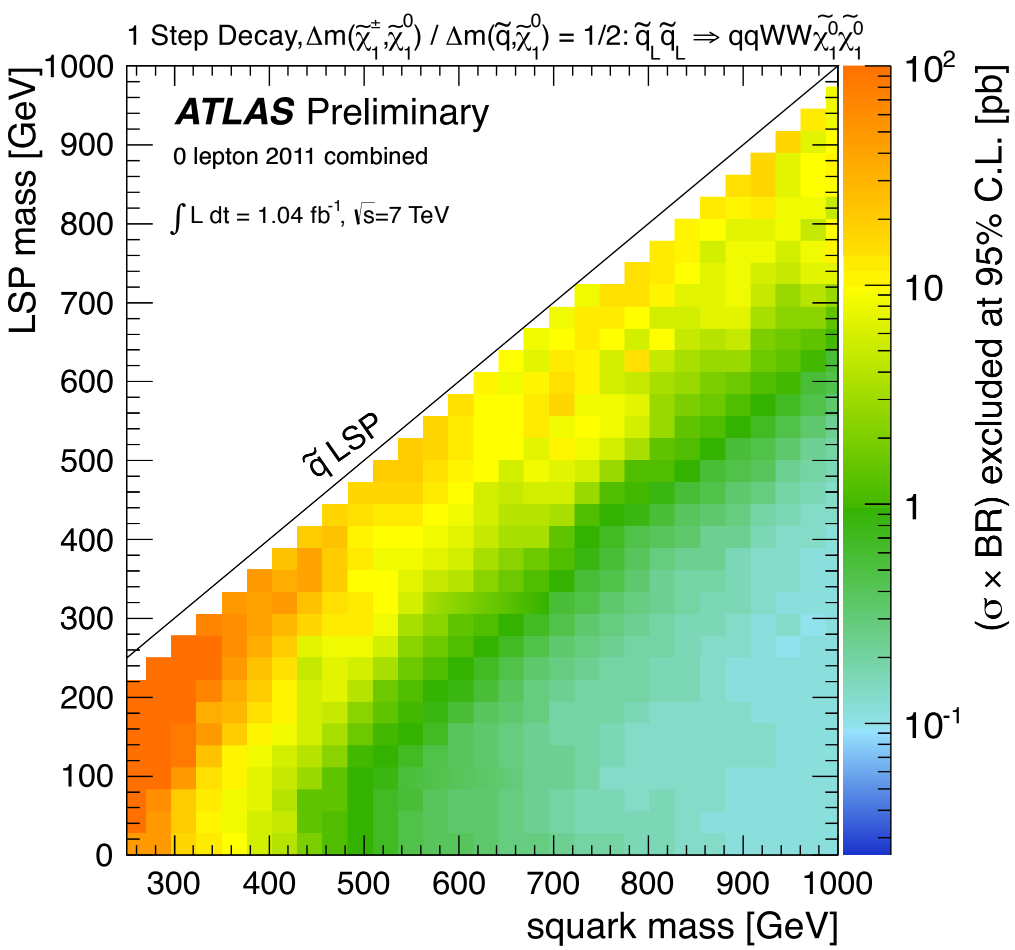
Add. interpr.: 1 step decay

- For Simplified models with a one-step squark decay:
  $$\tilde{q} \to q\tilde{\chi}_1^{\pm} \to qW\tilde{\chi}_1^0$$
  with chargino mass related to squark and LSP by:
  $$x = \frac{m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{q}_L,\tilde{g}} - m_{\tilde{\chi}_1^0}}$$

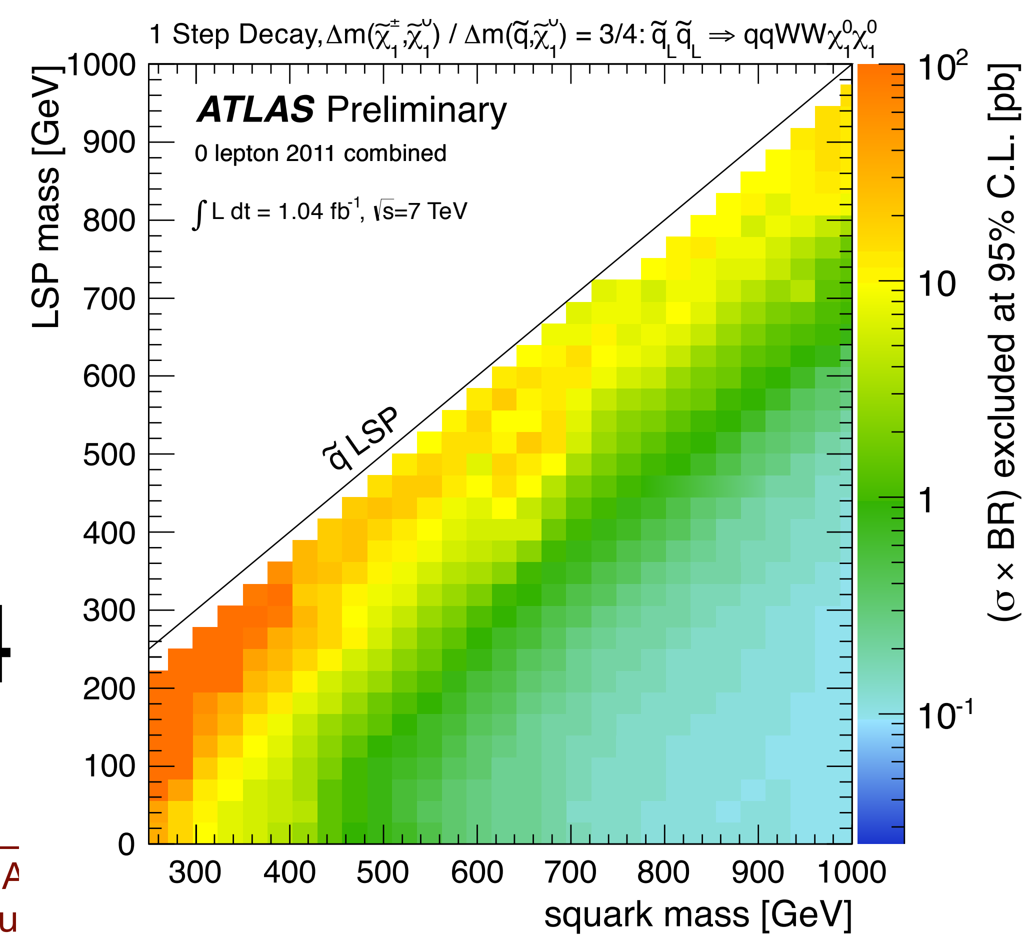
x=1/4



x=1/2



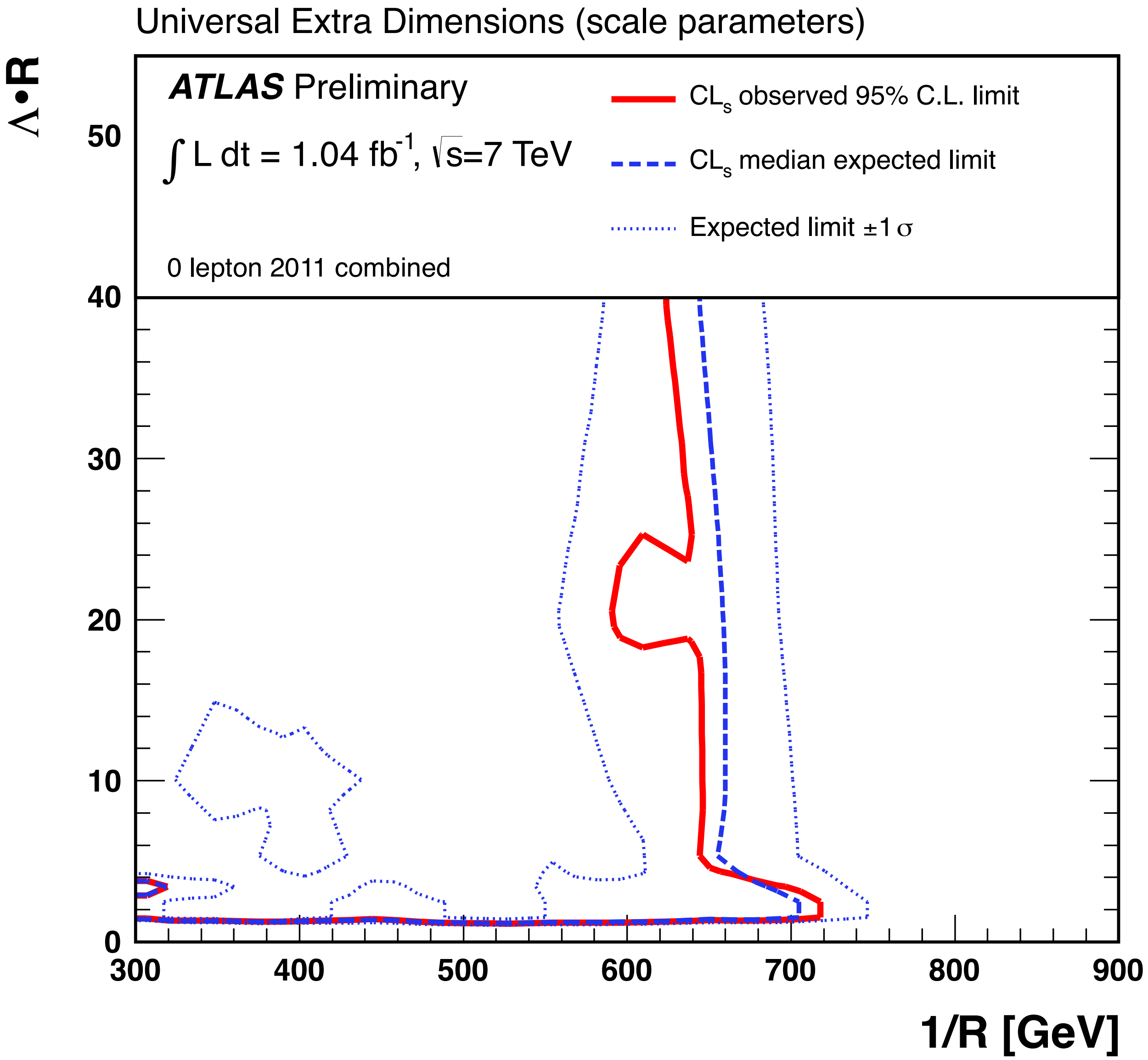
x=3/4



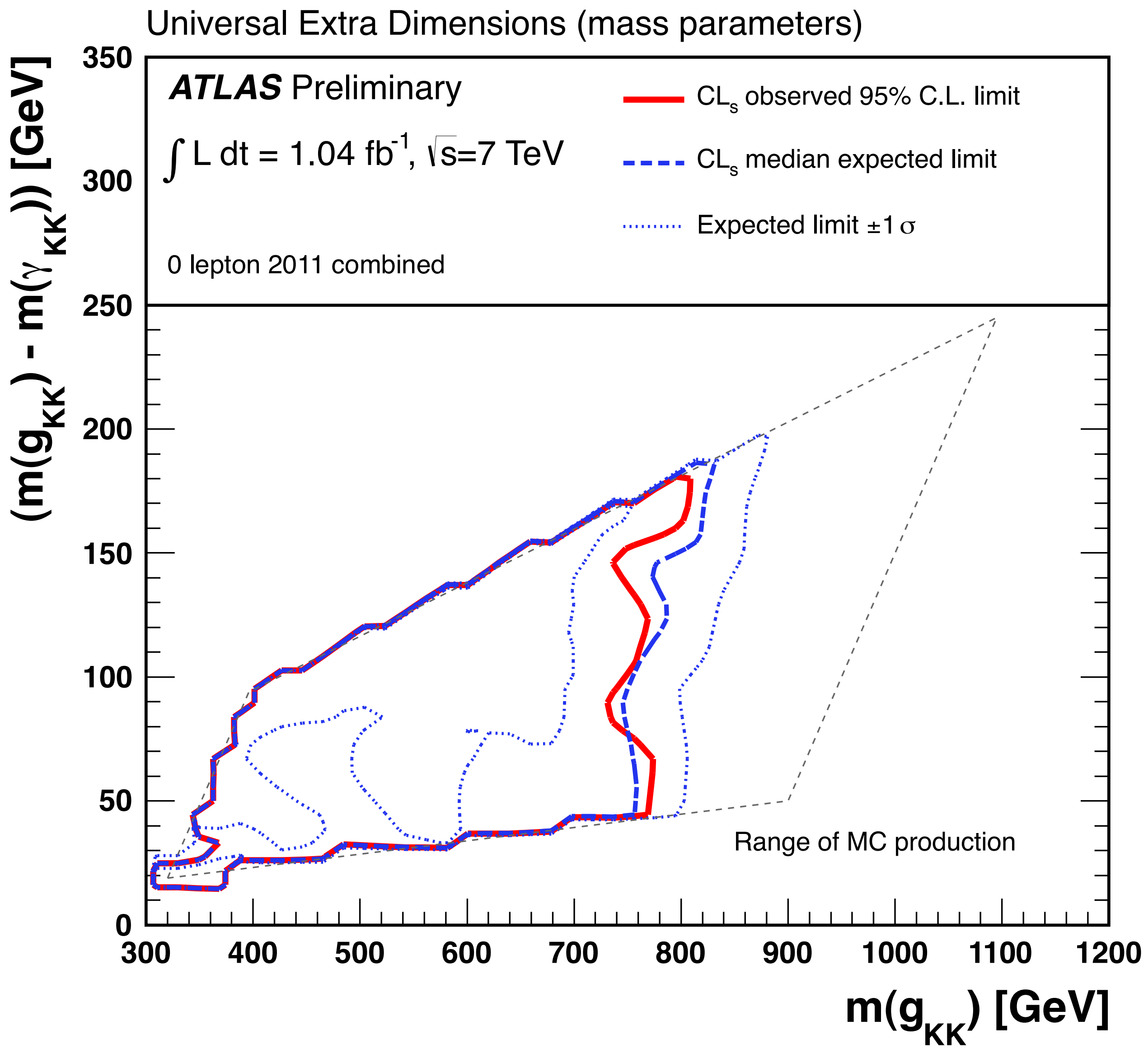
Add. interpr.:Extra dimensions

- Interpretation of results in UED models in terms of:

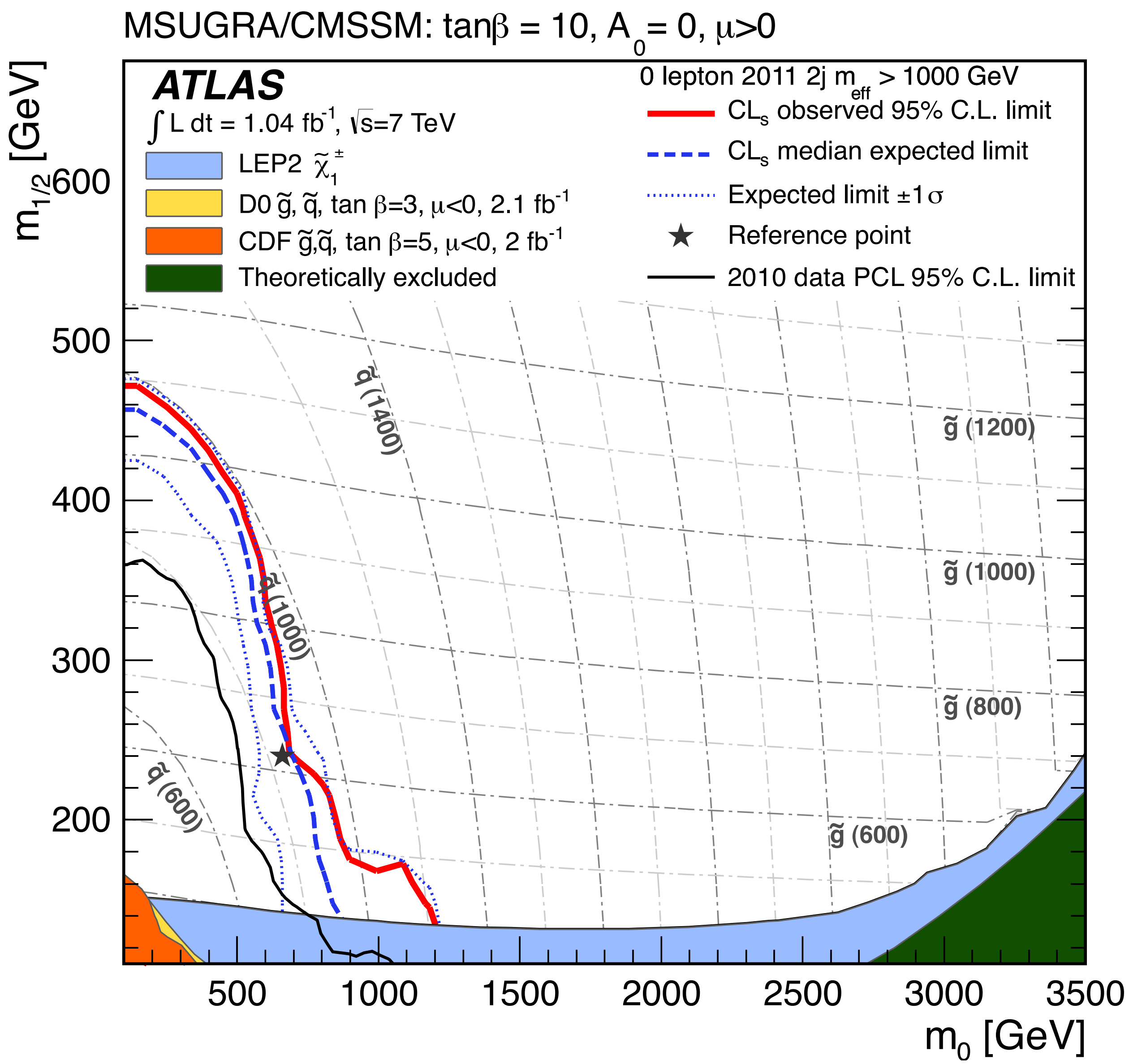
Compactification scale R^{-1} vs. Compression scale ΛR

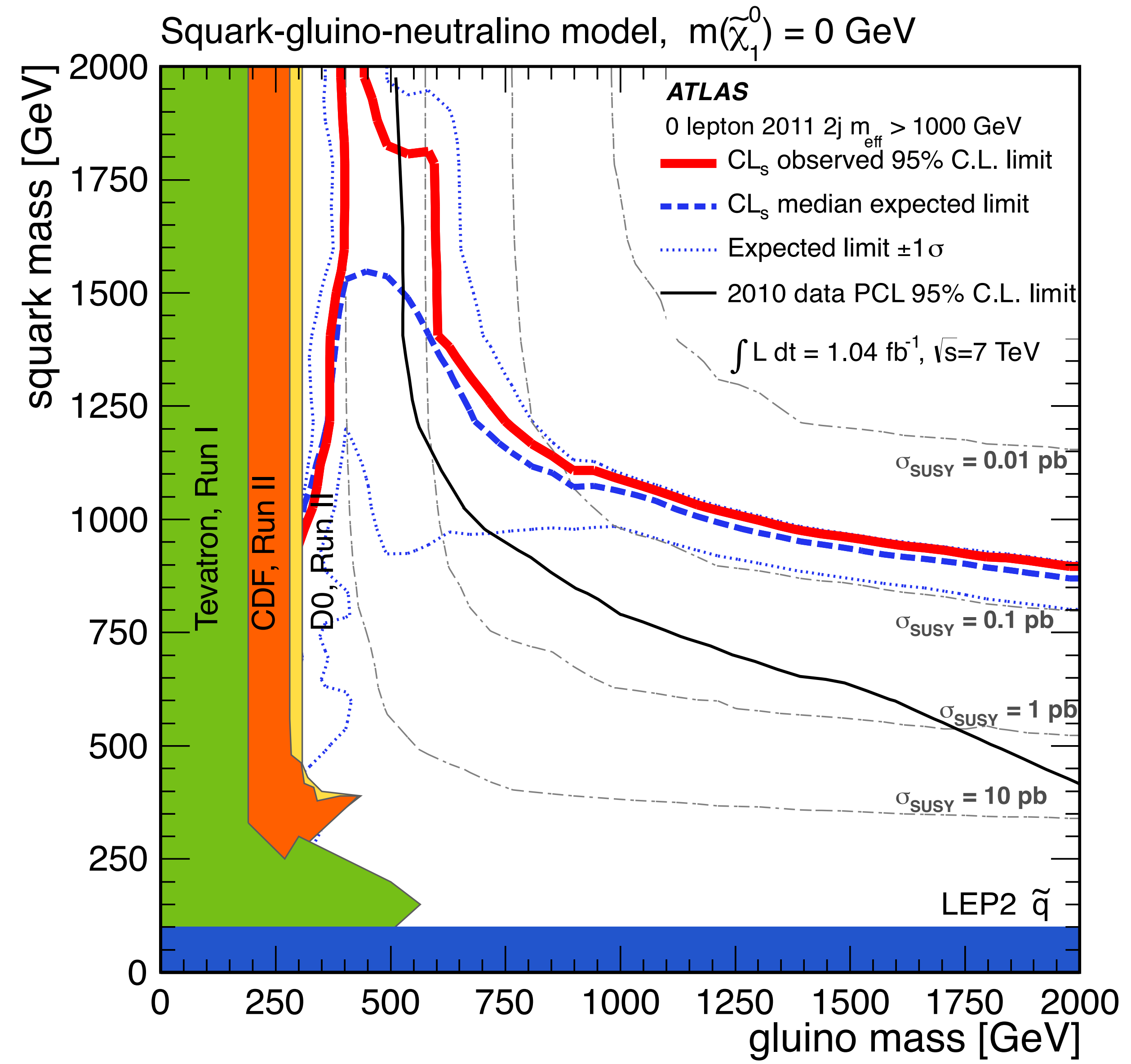


KK gluon mass vs. KK photon mass

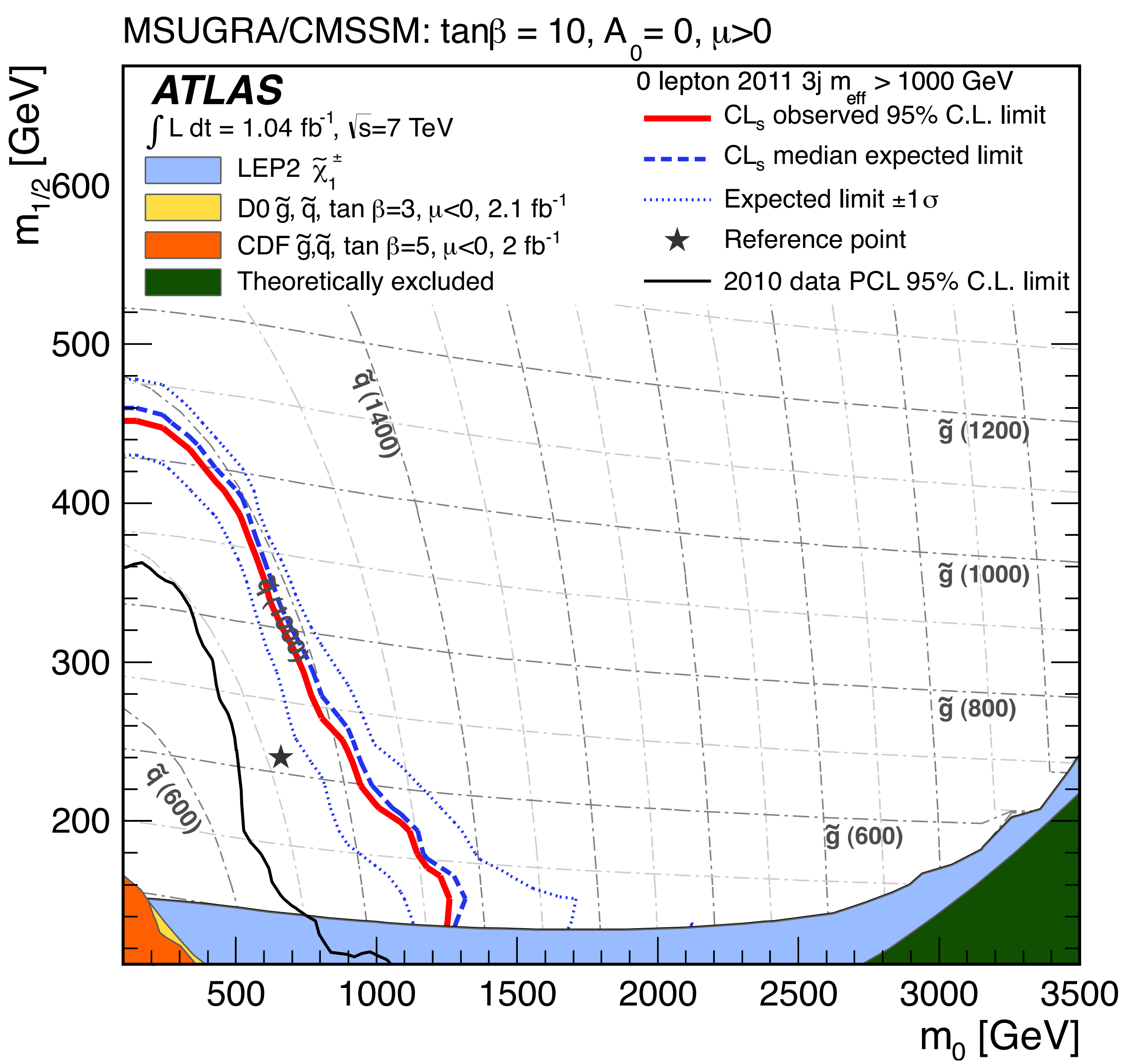


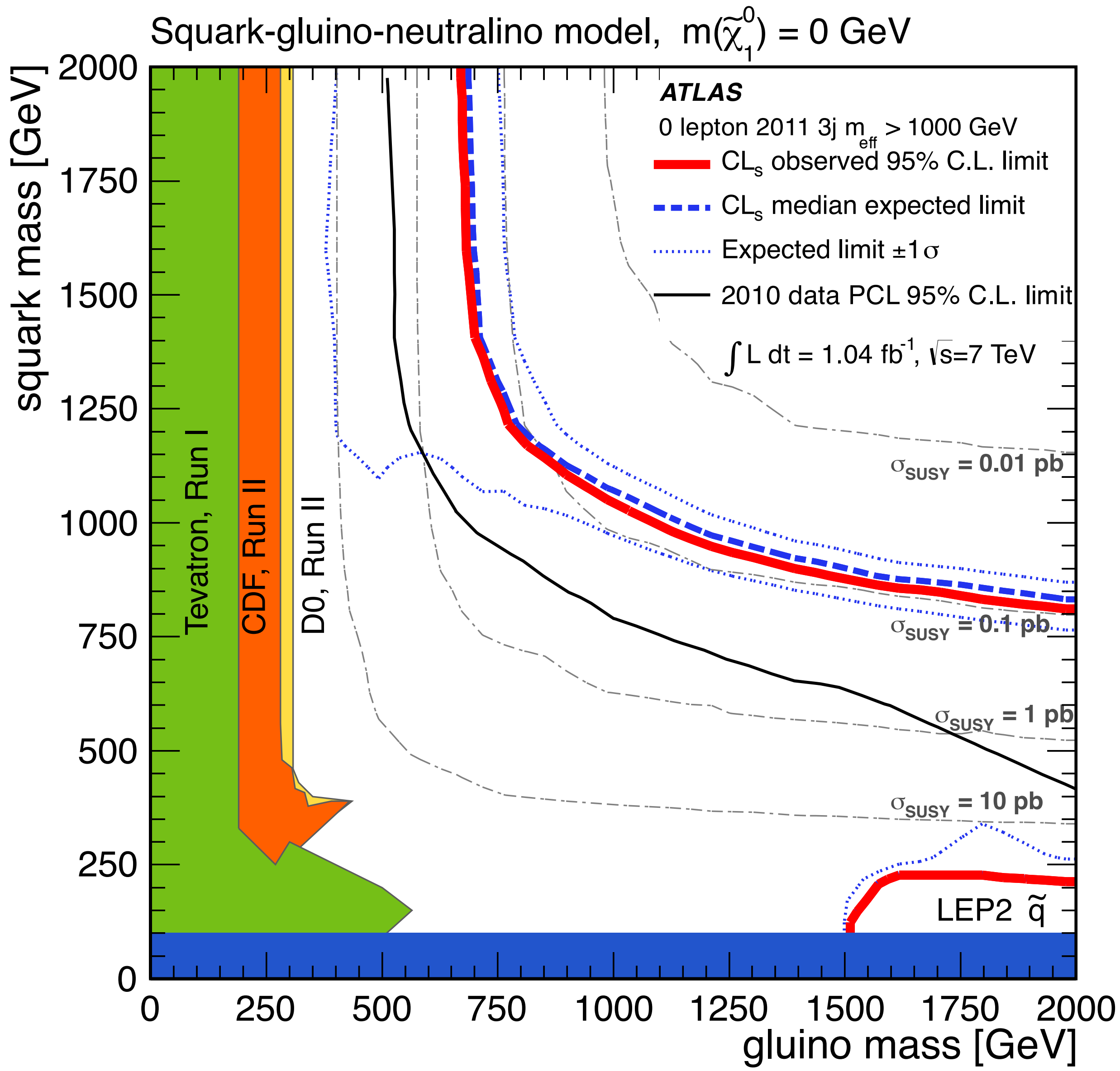
Exclusion per SR: Dijet



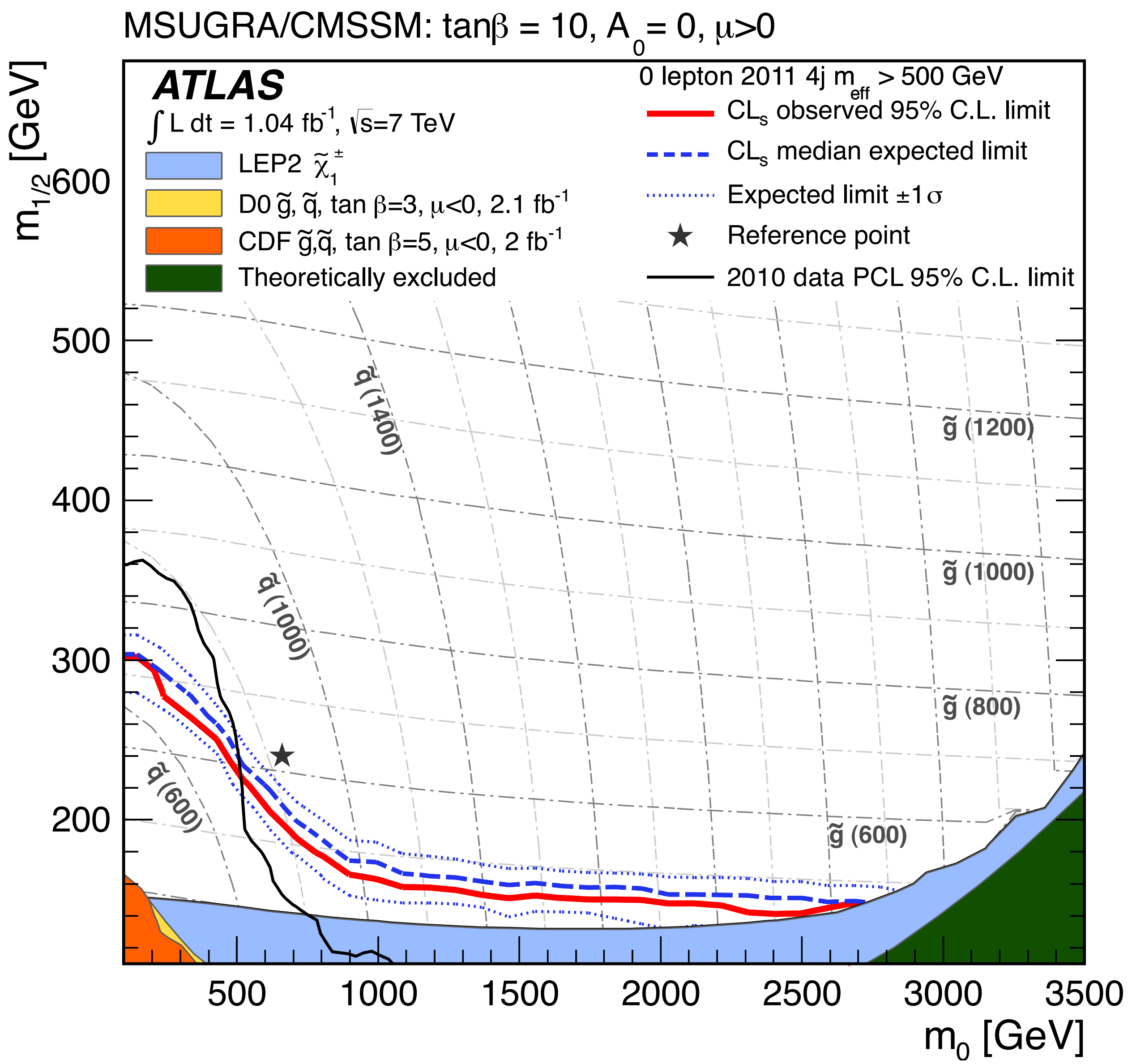


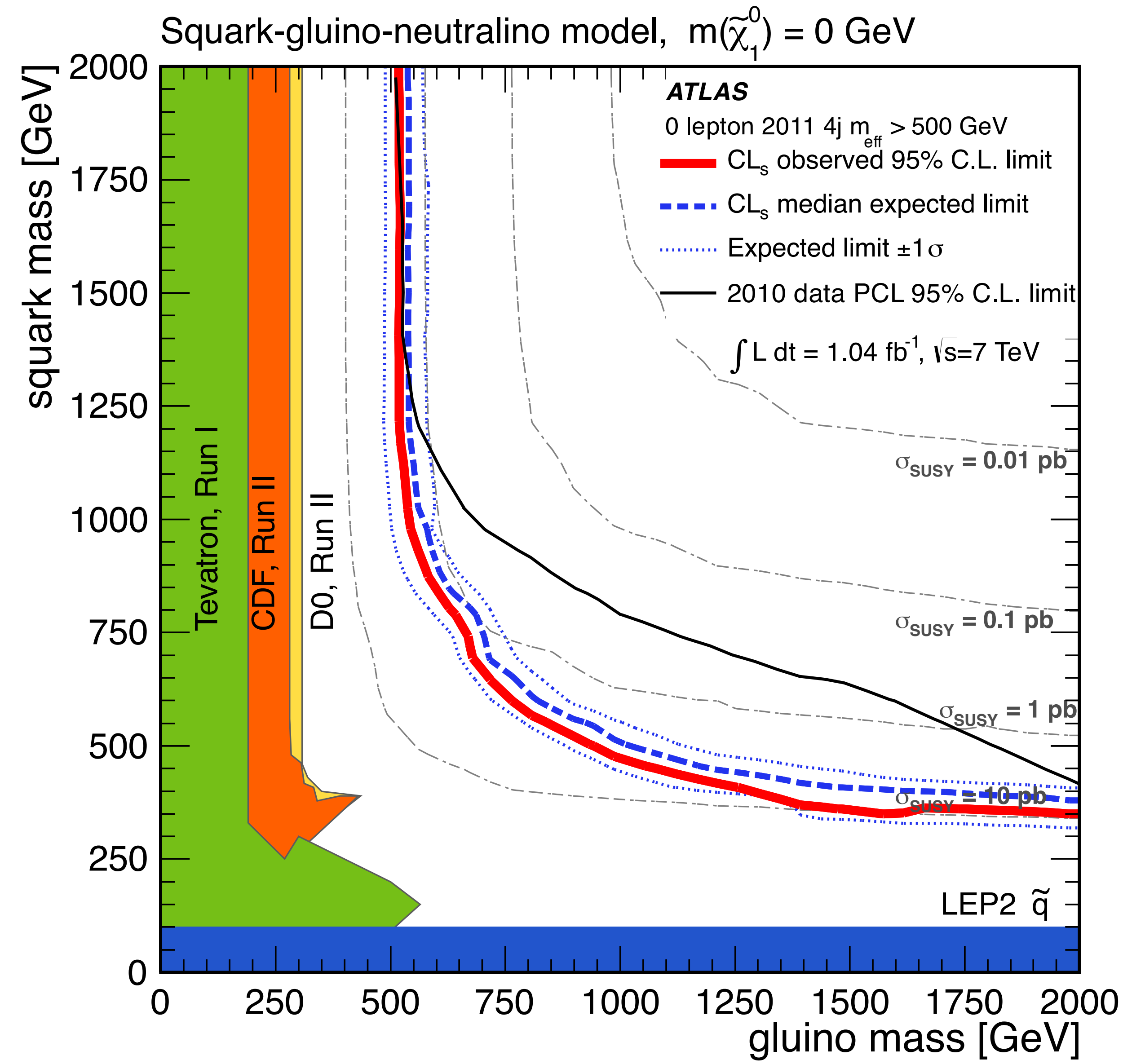
Exclusion per SR: three jet



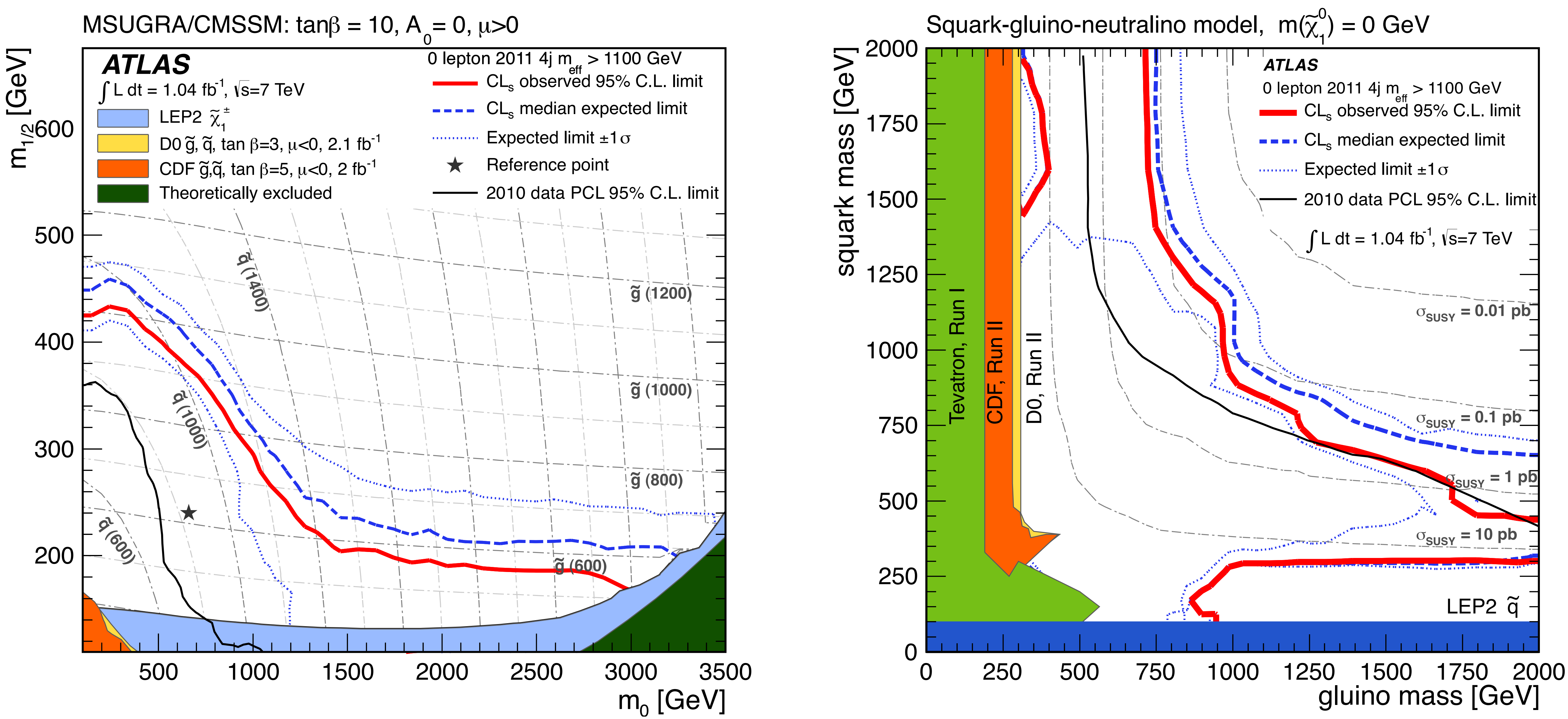


Exclusion per SR: 4 jet(500)

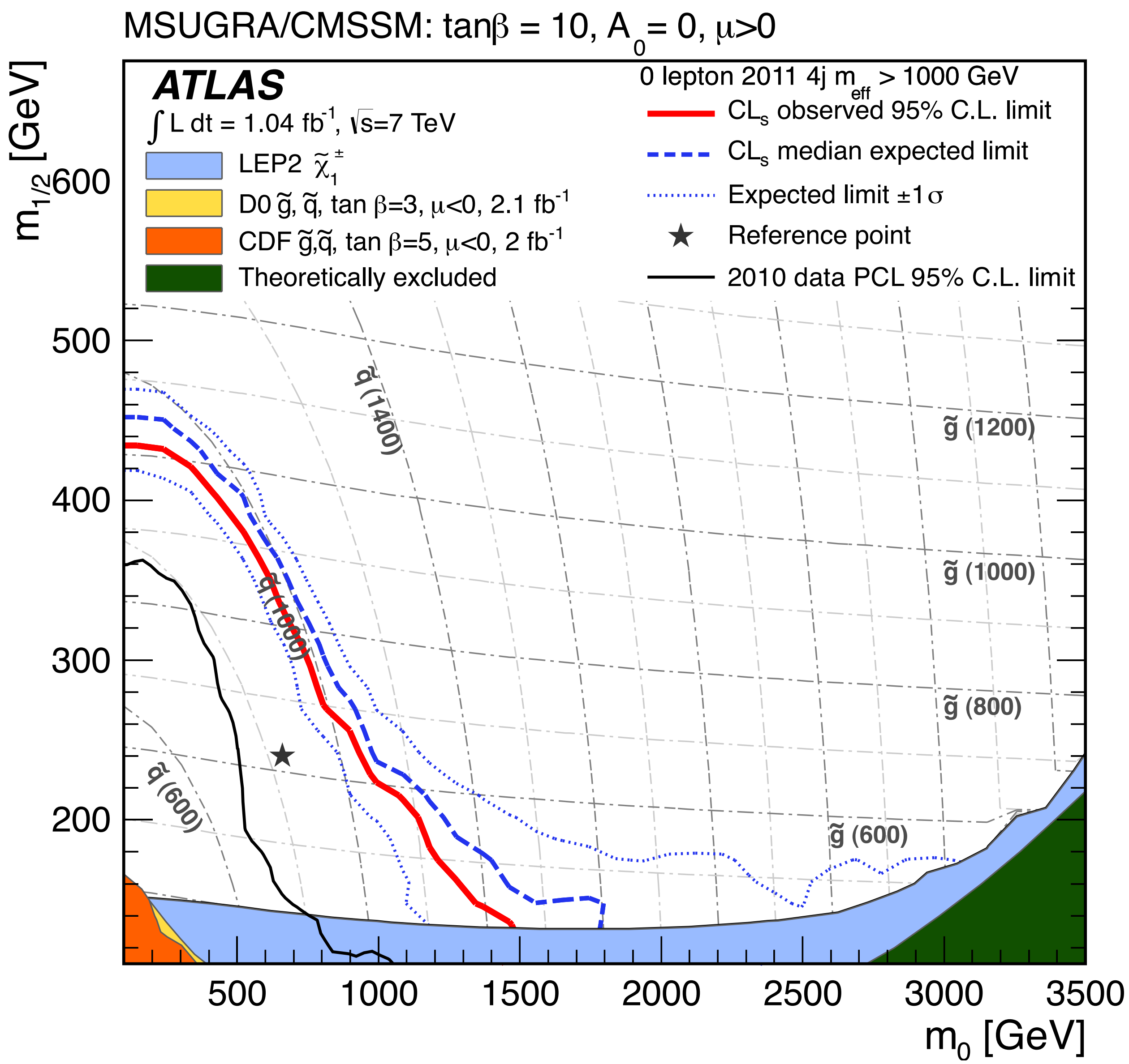


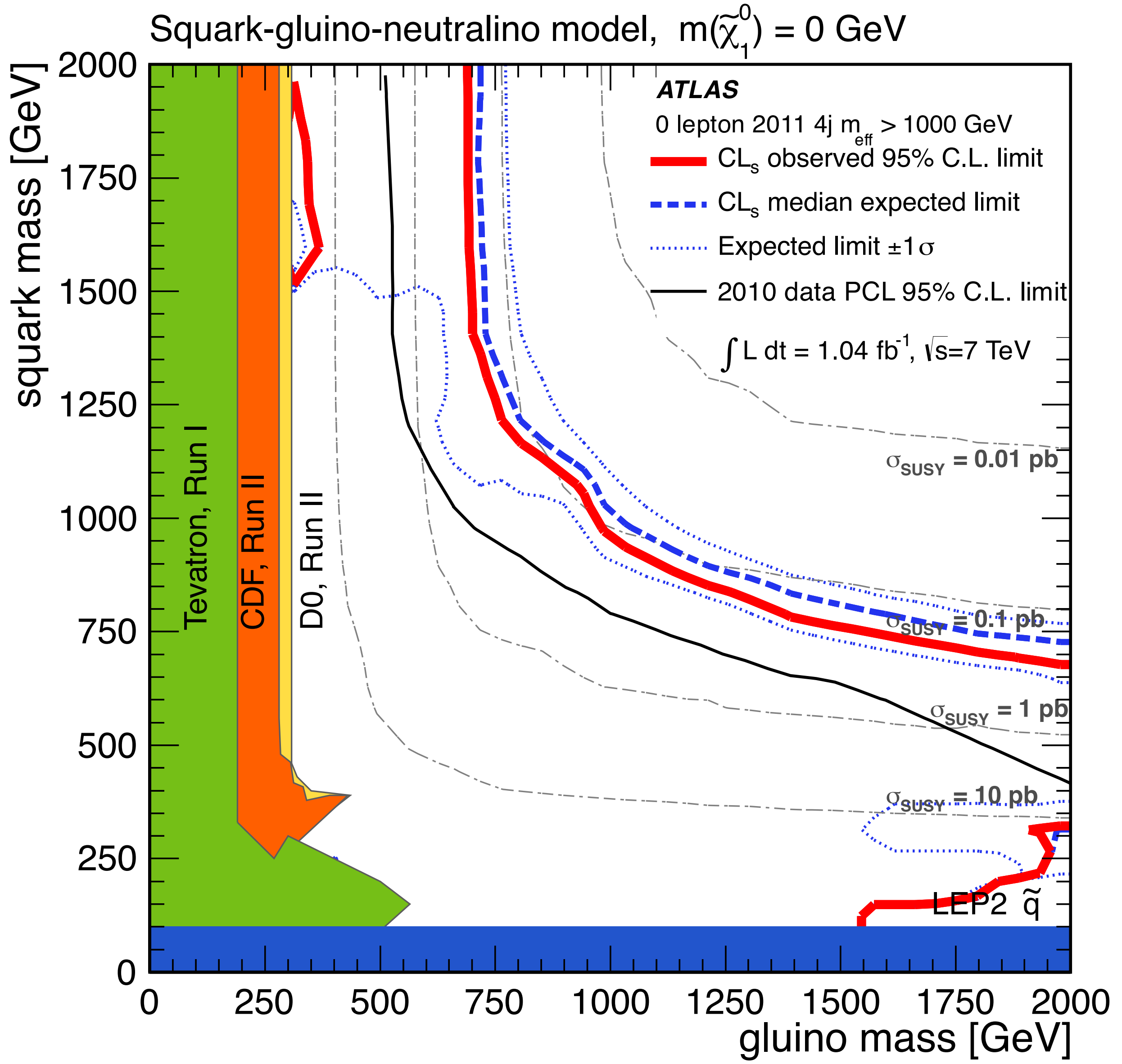


Exclusion per SR: 4 jet (1000)



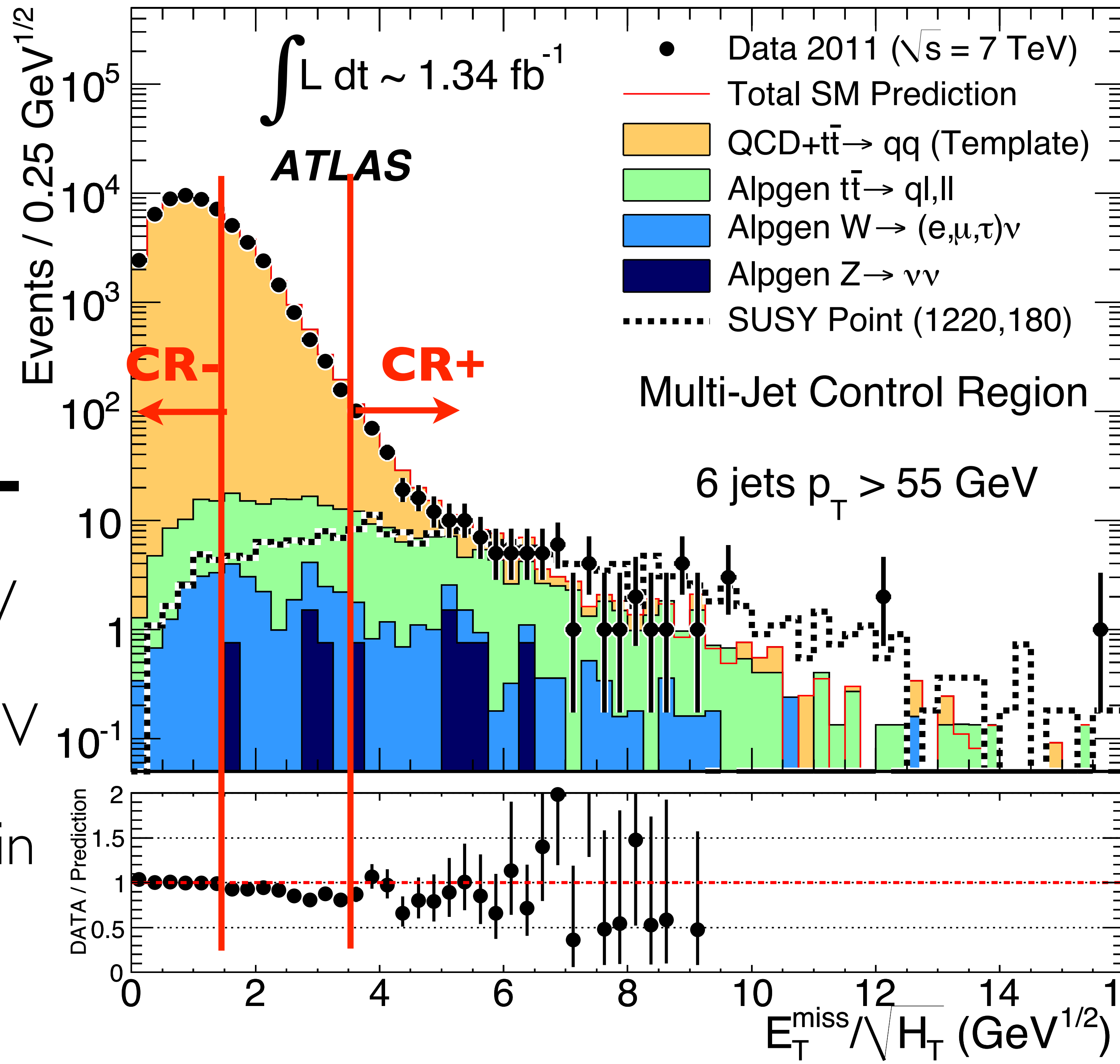
Exclusion per SR: High mass





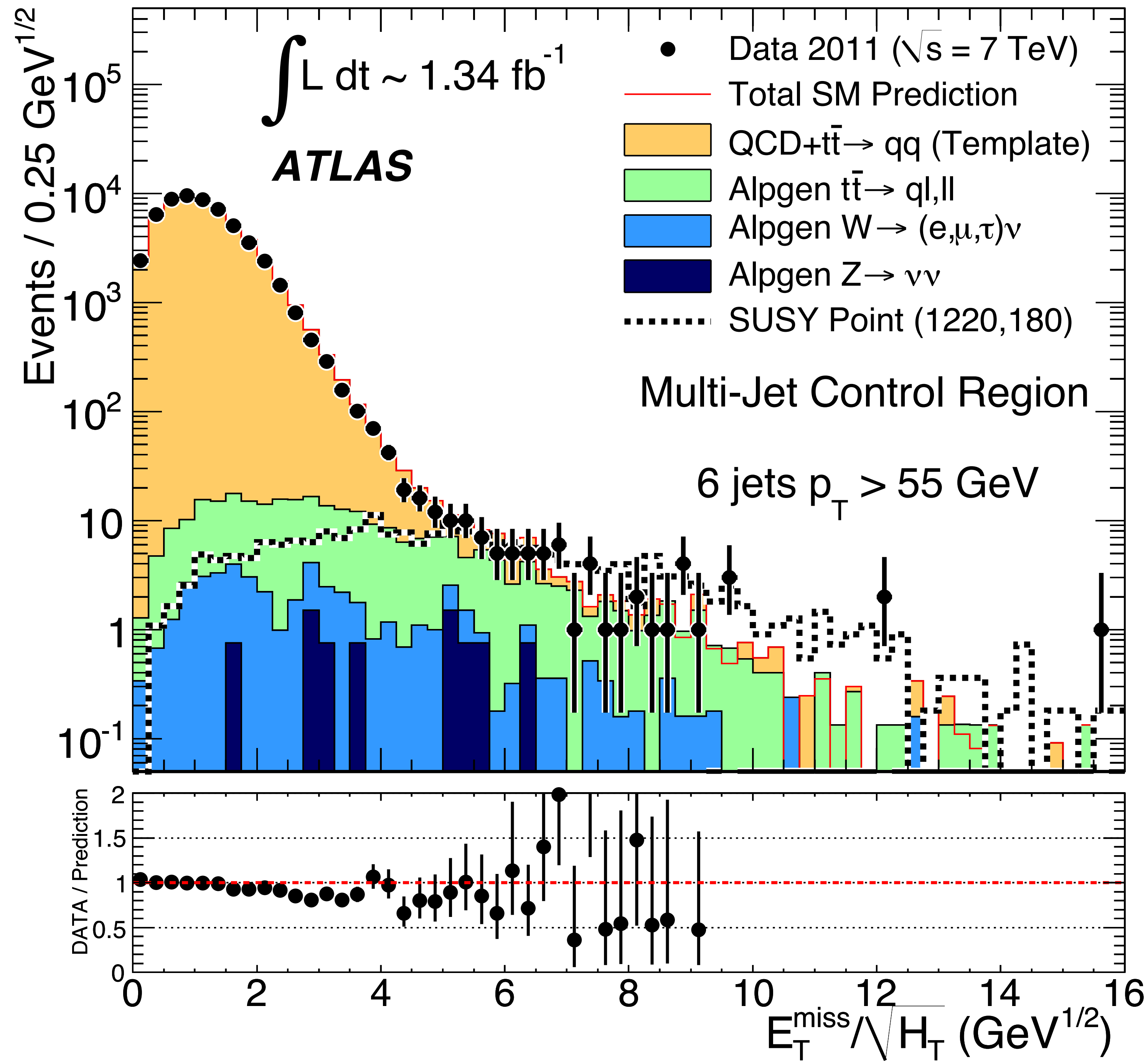
Control regions Multijets

- $E_T^{miss} / \sqrt{H_T}$ invariant under N_{jets}
  - $H_T = \sum p_T$
- Measure $E_T^{miss} / \sqrt{H_T}$ for lower jet multiplicity
- Then use:
  - Transfer factor: **CR+ / CR-**
  - CR- : $E_T^{miss}/\sqrt{H_T} < 1.5\ \sqrt{GeV}$
  - CR+ : $E_T^{miss}/\sqrt{H_T} > 3.5\ \sqrt{GeV}$
  - Taken from data in n_{jets}=4 bin (n_{jets}=5 bin) for SR with p_T>80 (p_T>55)



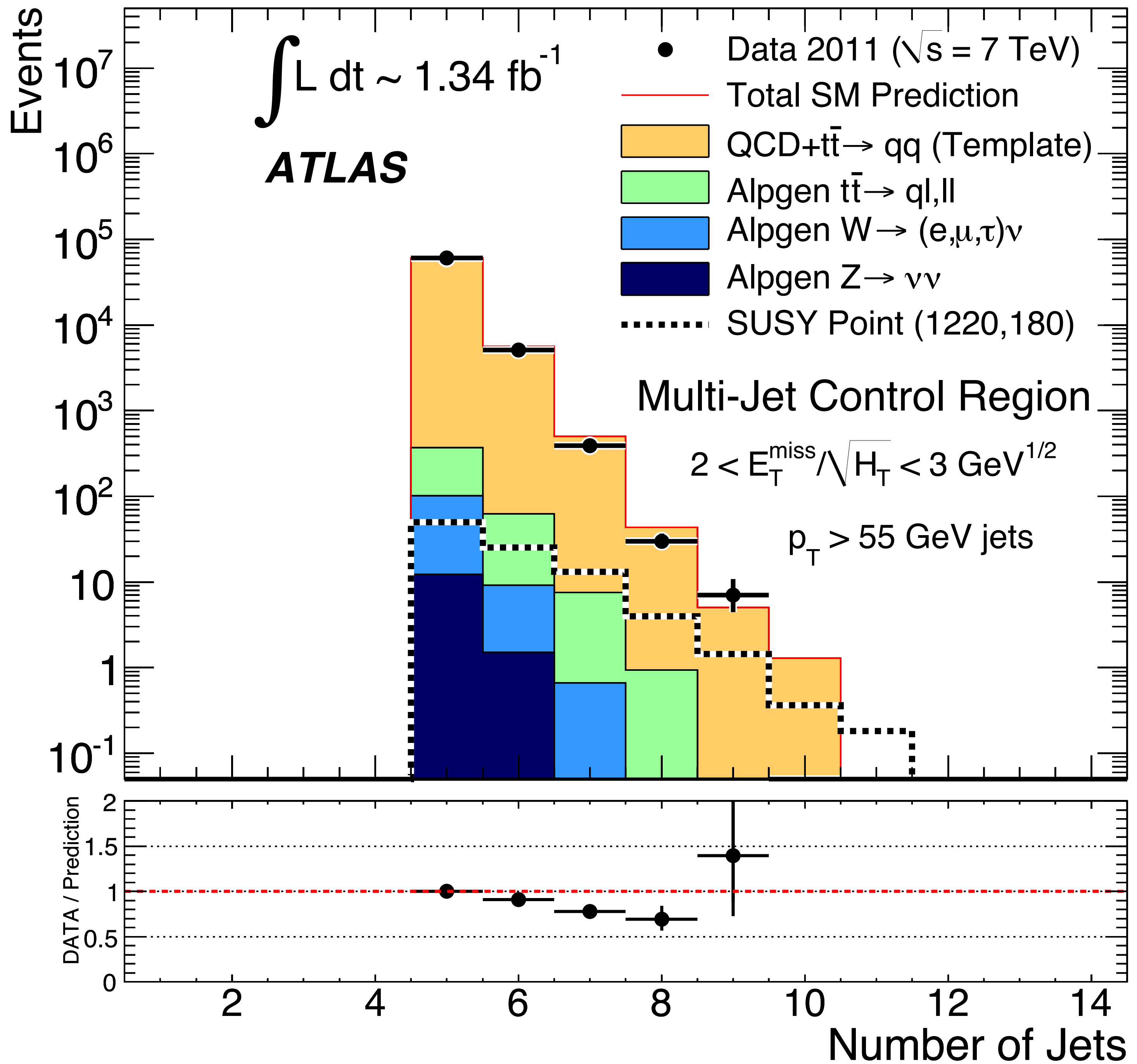
Multijets: Validation

- Validation of $E_T^{miss}/\sqrt{H_T}$ invariance assumption
- Template is taken from selection with N_{jet}=5 with p_T>55 GeV, normalised to region with $E_T^{miss}/\sqrt{H_T} < 1.5 GeV^{1/2}$



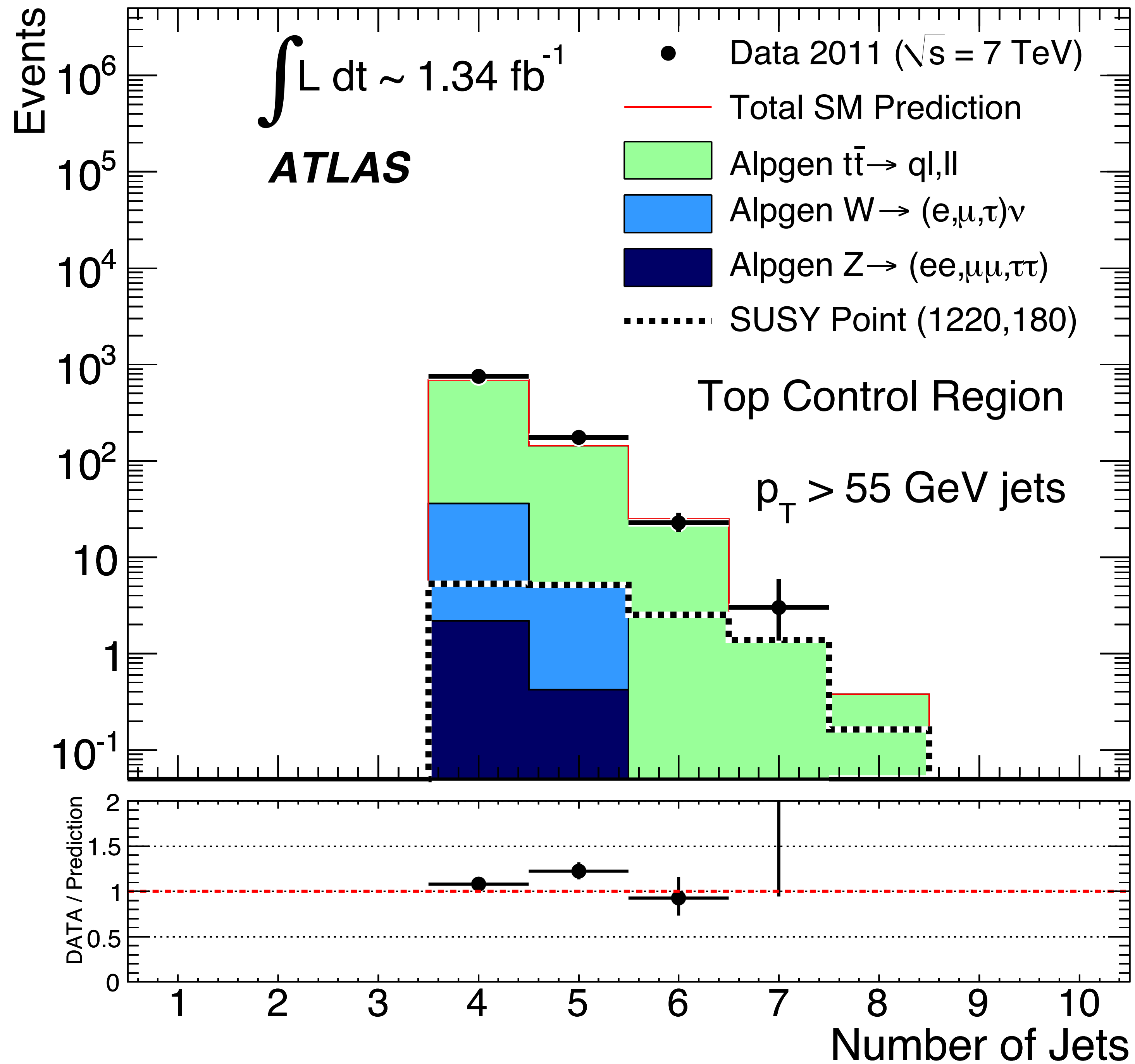
Multijets: Validation

- Validation of $E_T^{miss}/\sqrt{H_T}$ invariance assumption
- Template is taken from selection with $E_T^{miss}/\sqrt{H_T} < 1.5 GeV^{1/2}$, normalised to lowest bin



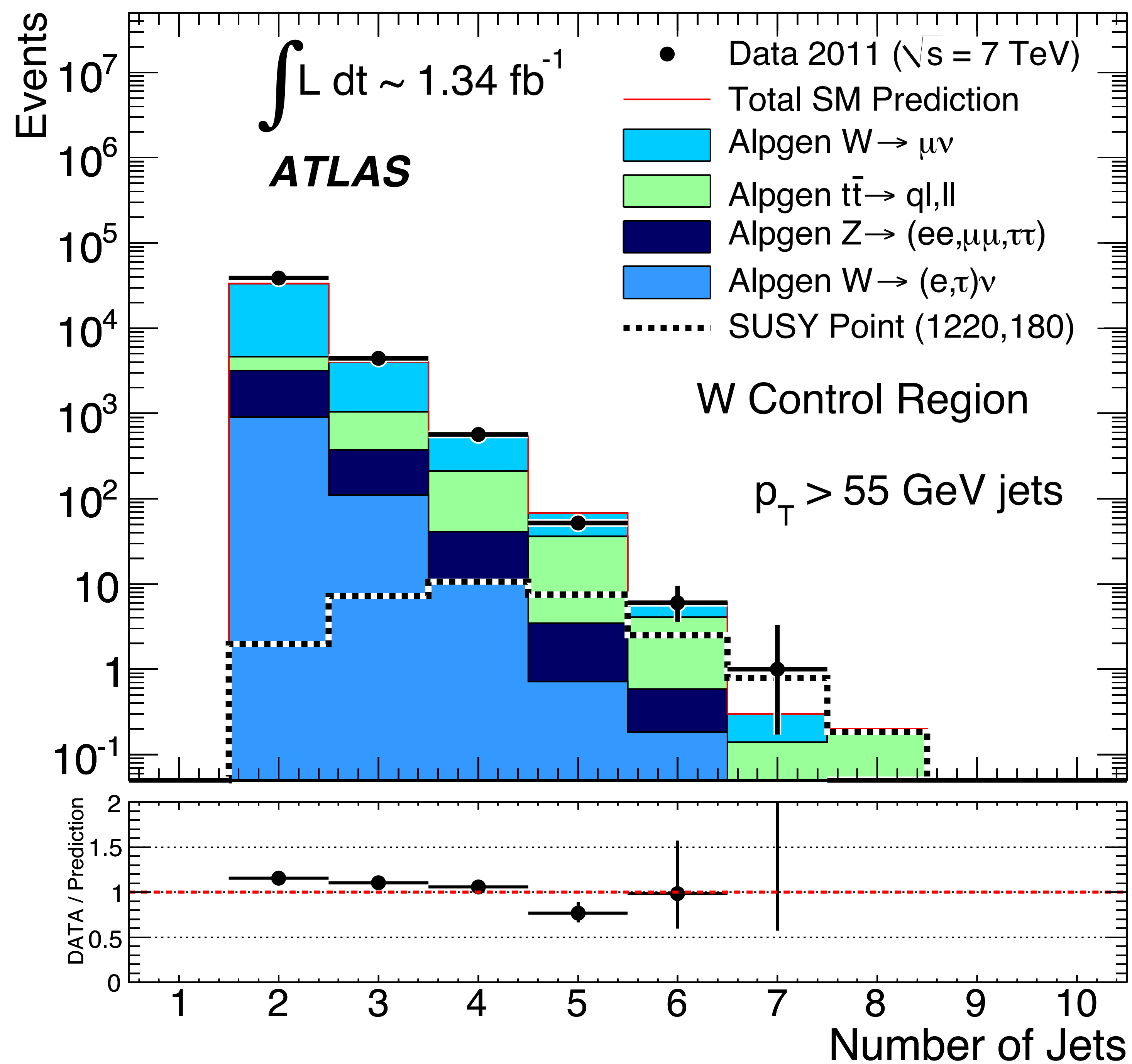
Multijets: Top CR

- **Top CR:**
  - Select 1 lepton
  - Require $40 > m_T(l, E_T^{miss}) > 100$
  - b-jet **tag**
- As example: CR Top for $p_T > 55$GeV



Multijets: W validation

- **W CR:**
  - Select 1 lepton
  - Require $40 > m_T(l, E_T^{miss}) > 100$
  - b-jet **veto**
- As example: CR W for $p_T > 55GeV$
- Estimation taken from simulation



Full results Multijets

Signal region	7j55	8j55	6j80	7j80
Multi-jets	26 ± 5.2	2.3 ± 0.7	19 ± 4	1.3 ± 0.4
$t\bar{t} \to \ell\,(\ell)\,X$	10.8 ± 6.7	$0^{+4.3}$	6.0 ± 4.6	$0^{+0.13}$
W + jets	0.95 ± 0.80	$0^{+0.13}$	0.34 ± 0.34	$0^{+0.13}$
Z + jets	$1.5^{+1.8}_{-1.5}$	$0^{+0.75}$	$0^{+0.75}$	$0^{+0.75}$
Total SM	$39.3^{+8.7}_{-8.5}$	$2.3^{+4.4}_{-0.7}$	25.8 ± 6.1	$1.3^{+0.9}_{-0.4}$
Data	45	4	26	3
$N^{95\%}_{\mathrm{BSM,max}}$	26.0	11.2	16.3	6.0
$(\sigma^{95\%}_{\mathrm{BSM,max}} \times \epsilon)/\mathrm{fb}$	19.4	8.4	12.2	4.5
p_{SM}	0.30	0.36	0.49	0.16

Statistical method

Simultaneous likelihood fit to Signal Region+ 5 Control Regions in each channel

- Correlations between Control Regions taken into account
  - like tagging efficiencies and jet energy scale

$$L(\boldsymbol{n}|\mu, \boldsymbol{b}, \boldsymbol{\theta}) = P_{\rm SR} \times P_{\rm WR} \times P_{\rm TR} \times P_{\rm ZRa} \times P_{\rm ZRb} \times P_{\rm QR} \times C_{\rm Syst}\,.$$

- To combine the 5 channels: take channel with best expected limit at each point