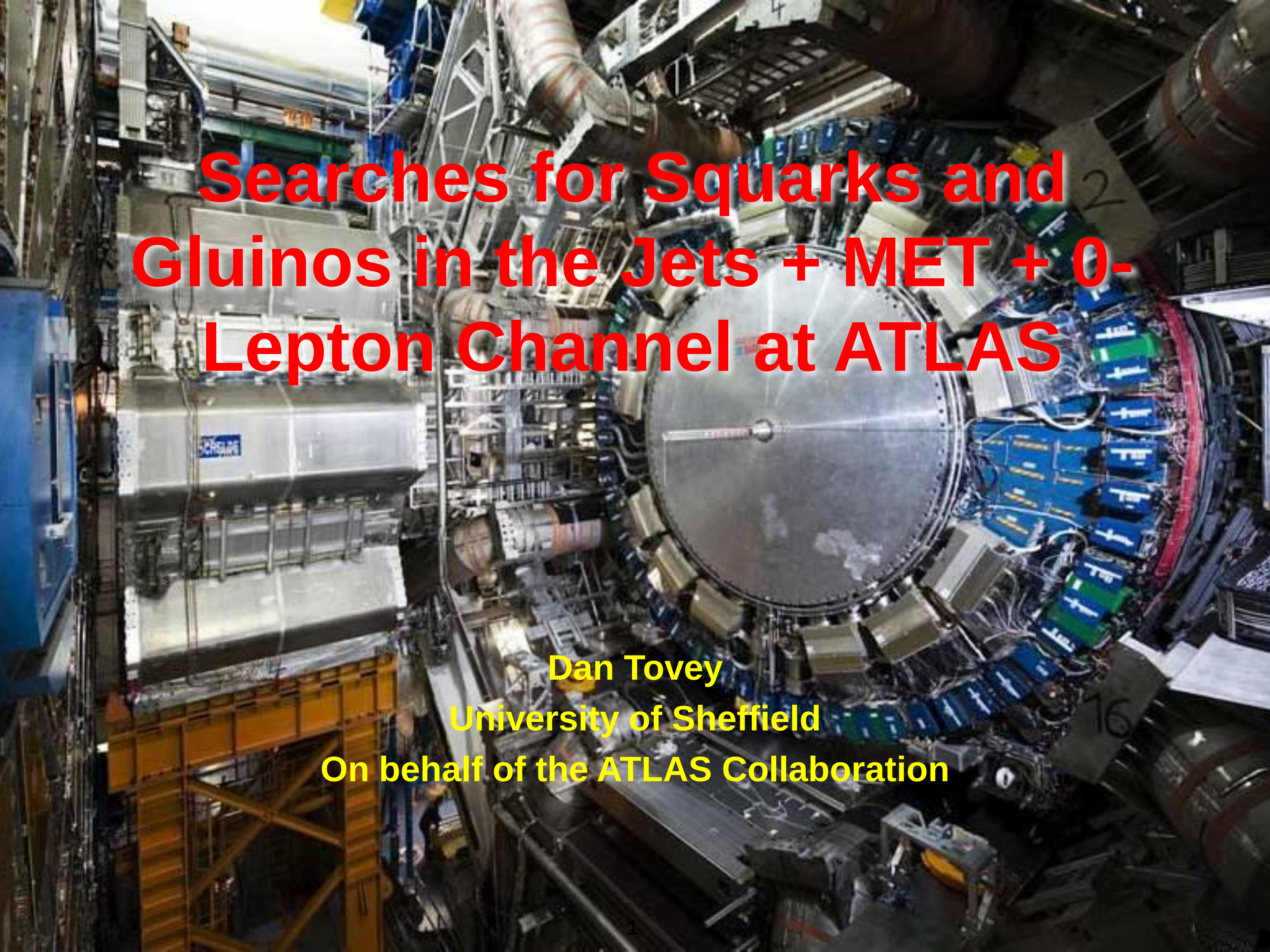


Searches for Squarks and Gluinos in the Jets + MET + 0-Lepton Channel at ATLAS

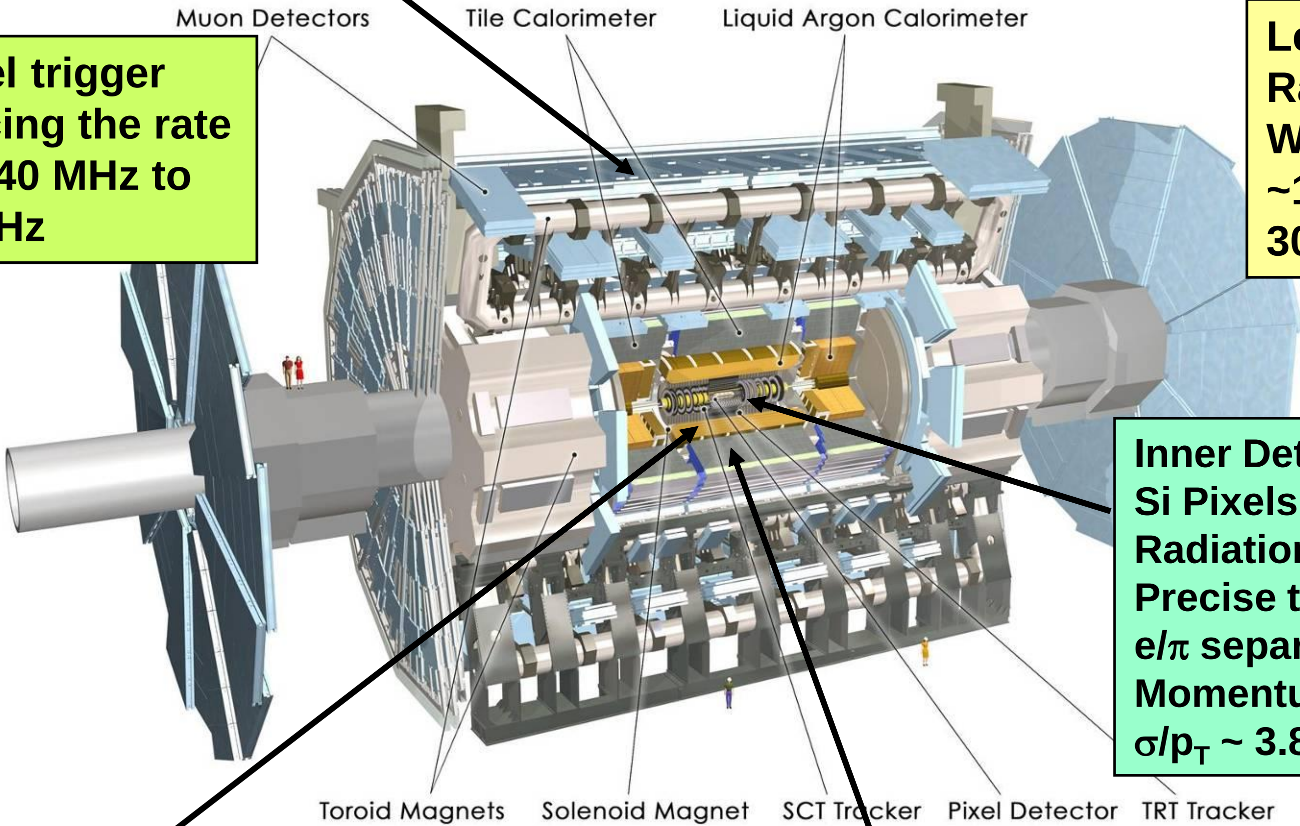
Dan Tovey
University of Sheffield
On behalf of the ATLAS Collaboration

The ATLAS Detector

Muon Spectrometer (|η|<2.7): air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

3-level trigger reducing the rate from 40 MHz to ~200 Hz

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

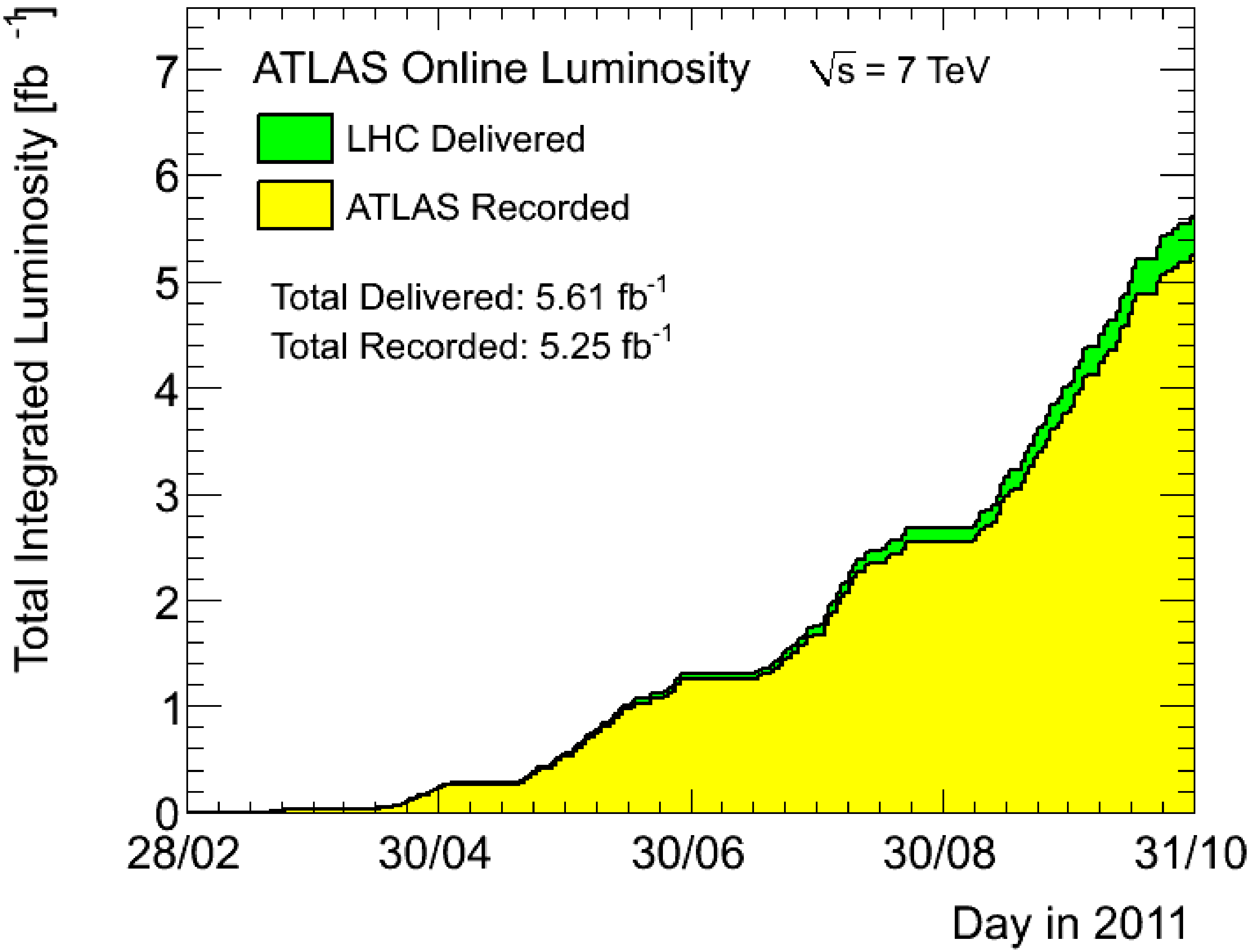


Inner Detector (|η|<2.5, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution (η=0):
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\text{GeV}) \oplus 0.015$

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

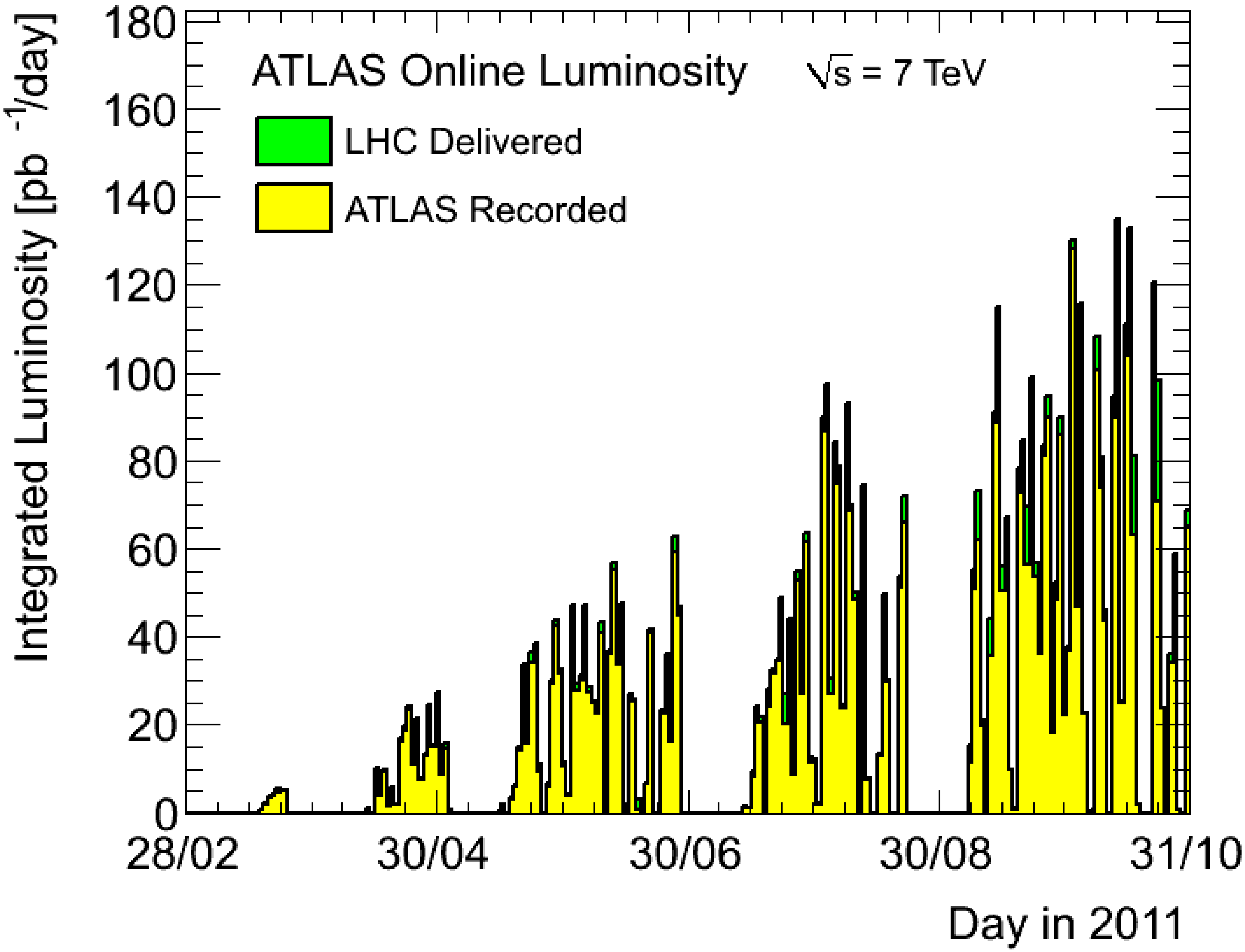
HAD calorimetry (|η|<5)
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

Luminosity



ATLAS Online Luminosity
√s = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 5.61 fb-1
Total Recorded: 5.25 fb-1
Total Integrated Luminosity [fb -1]
0
1
2
3
4
5
6
7
28/02
30/04
30/06
30/08
31/10
Day in 2011

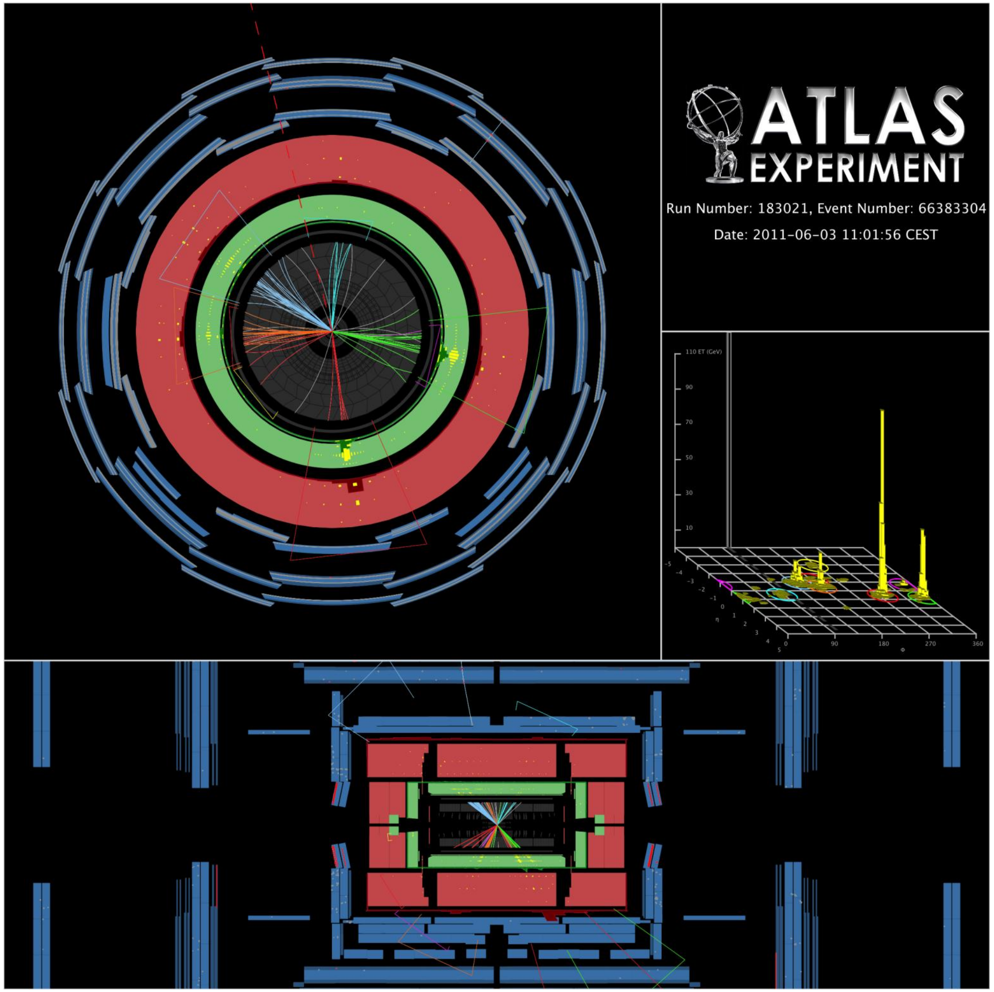
Luminosity



ATLAS Online Luminosity
$\sqrt{s}$ = 7 TeV
LHC Delivered
ATLAS Recorded
Integrated Luminosity [pb $^{-1}$/day]
0
20
40
60
80
100
120
140
160
180
28/02
30/04
30/06
30/08
31/10
Day in 2011

Motivation

- Strong production (squarks, gluinos) dominates SUSY cross-section unless large mass hierarchy (1)
- LSP/DM production generates MET even without leptons (2)
- SM real MET signature usually accompanied by leptons (except Z→$\nu\nu$) (3)
- Implies require jets (1), MET (2) and veto leptonic events (3)
- Remaining: QCD fake/real MET events, fake-jets/missed leptons, and Z→$\nu\nu$.



Strategy

- Search for production of strongly interacting sparticles (squarks/gluinos) decaying to jets and invisible LSPs
- Analysis of 1.04 fb^{-1} of data from early 2011 presented at EPS
- Similar strategy to that used with 2010 data (presented at Moriond 2011)
- Select events with jets + MET and no identified leptons
- Main backgrounds:
  - QCD jets (fake MET and HF decays),
  - Top pairs (semi/fully-leptonic) with lepton missed or faking jet (τ)
  - W(→lν)+jetswith lepton missed or faking jet (τ)
  - Z(→νν)+jets (irreducible)
- Lepton veto (p_T>20 GeV) supresses top and W+jets backgrounds

Signal Regions

- Signal Region selections designed for sensitivity to specific topologies / classes of models
- Large n_{jet} focuses on gluino-dominated / high m_0 (CMSSM/MSUGRA) models
- Low n_{jet} sensitive to squark-dominated / low m_0 models
- 4-jet M_{eff}>500 GeV SR targets low mass-splitting models

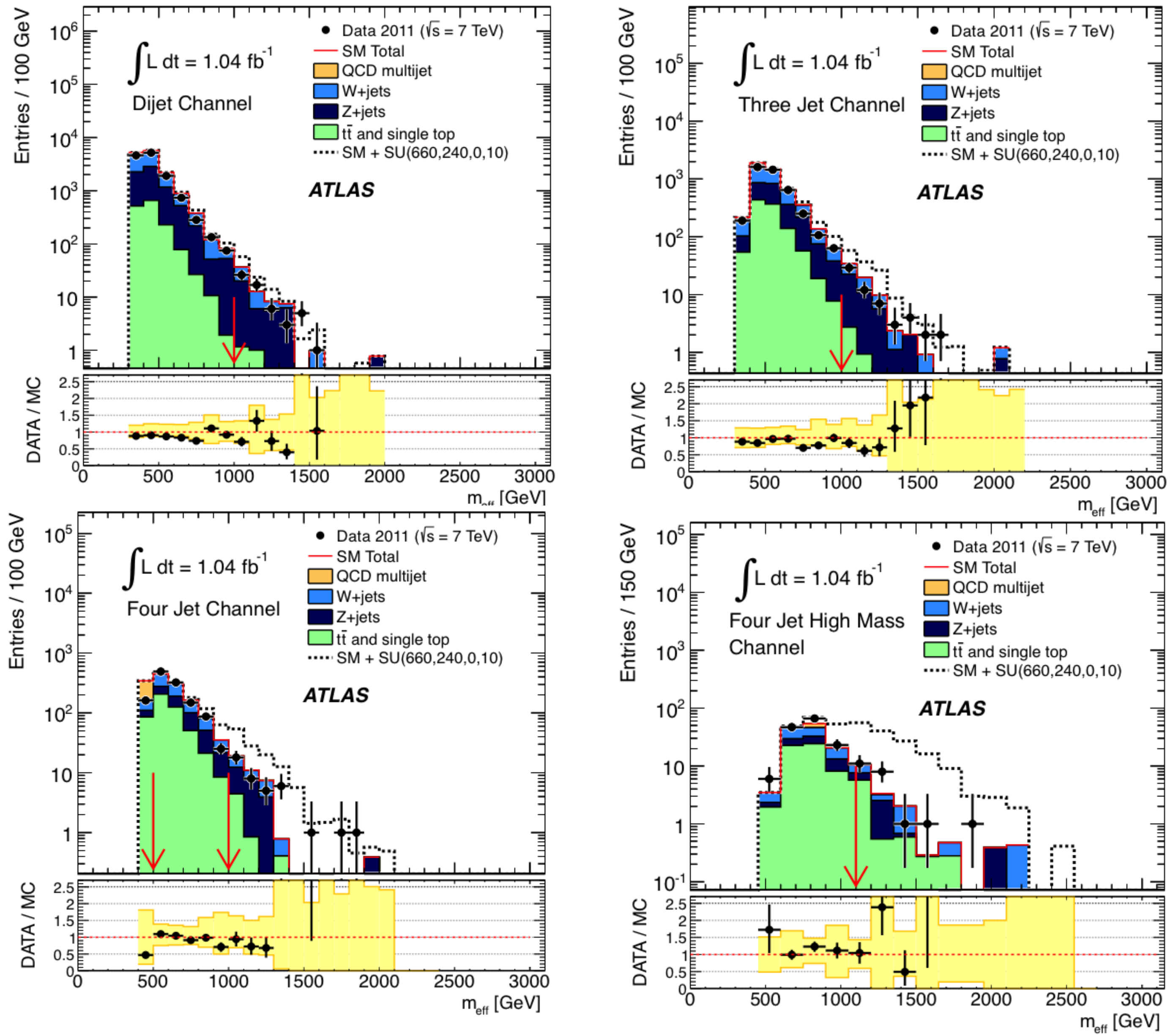
Signal Region	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	$> 500/1000$	> 1100

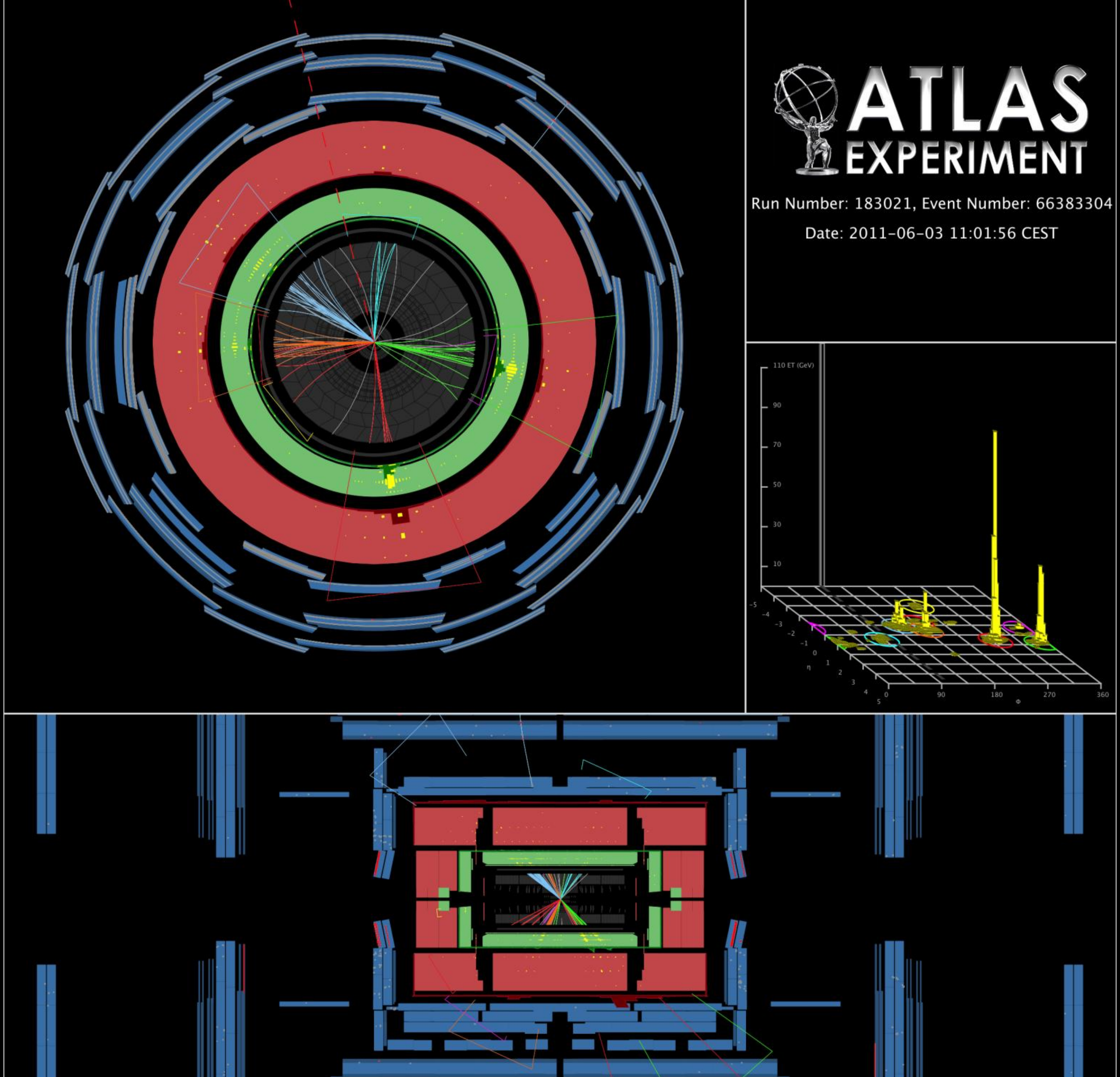
Signal Regions

- MET and leading jet p_T cuts protect against trigger turn-on
- 'Effective mass' scalar sum of jet p_T and MET
  - Number of jets used differs between SRs
- $\Delta\phi$(j,MET) cuts (leading 3 jets) reject QCD jet background where MET produced in association with a single jet
- MET/M_{eff} cuts select topology where jets point away from MET

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

Signal Region Meff Distributions



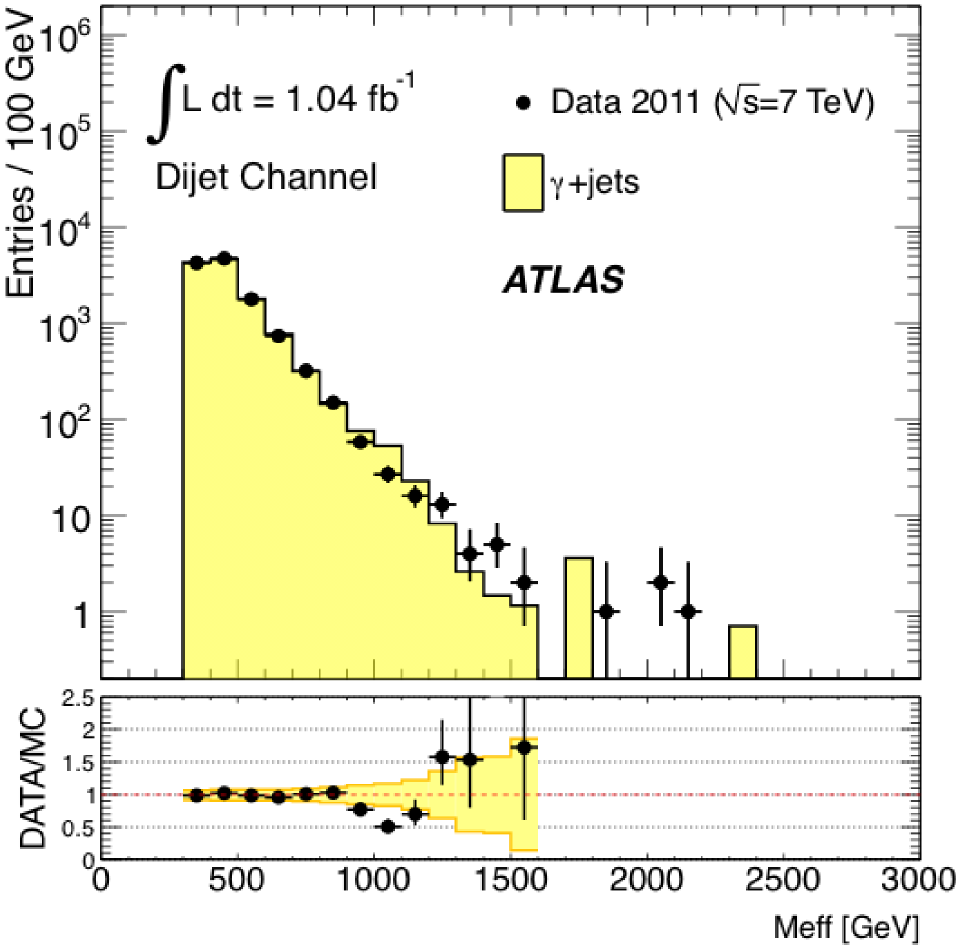

ATLAS
EXPERIMENT
Run Number: 183021, Event Number: 66383304
Date: 2011-06-03 11:01:56 CEST
110 ET (GeV)
90
70
50
30
10
η
Φ
0
90
180
270
360

Background Estimation

- SM backgrounds estimated using background-enriched data control regions (CR), with MC (ALPGEN or MC@NLO) or data-driven 'transfer factors' (TF) used to translate to signal regions (SR)
- Correlations between CR's from cross-contamination of backgrounds taken into account with CR-SR TFs.
- Backgrounds in SR obtained from coherent likelihood fit to CR observations, taking into account correlated (e.g. JES) and uncorrelated (e.g. MC stats) TF uncertainties
- Many correlated uncertainties largely cancel through use of CR/SR TF ratio (e.g. JES, PDF etc.)

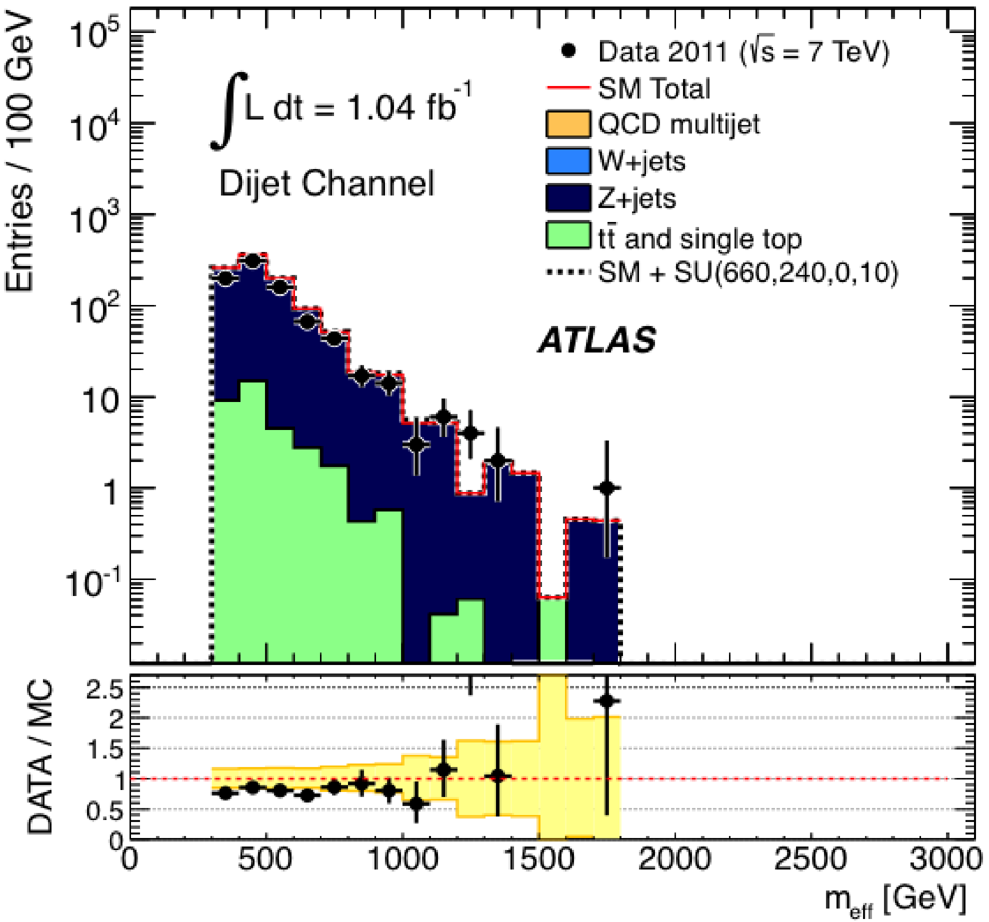
CR1a: Z+Jets Background

- Estimated with two independent CRs
- CR1a selects γ+jets events and adds γp_T to MET to simulate Z(→υυ) + jets events
- TF obtained from first principles using corrections for photon acceptance, efficiency etc.



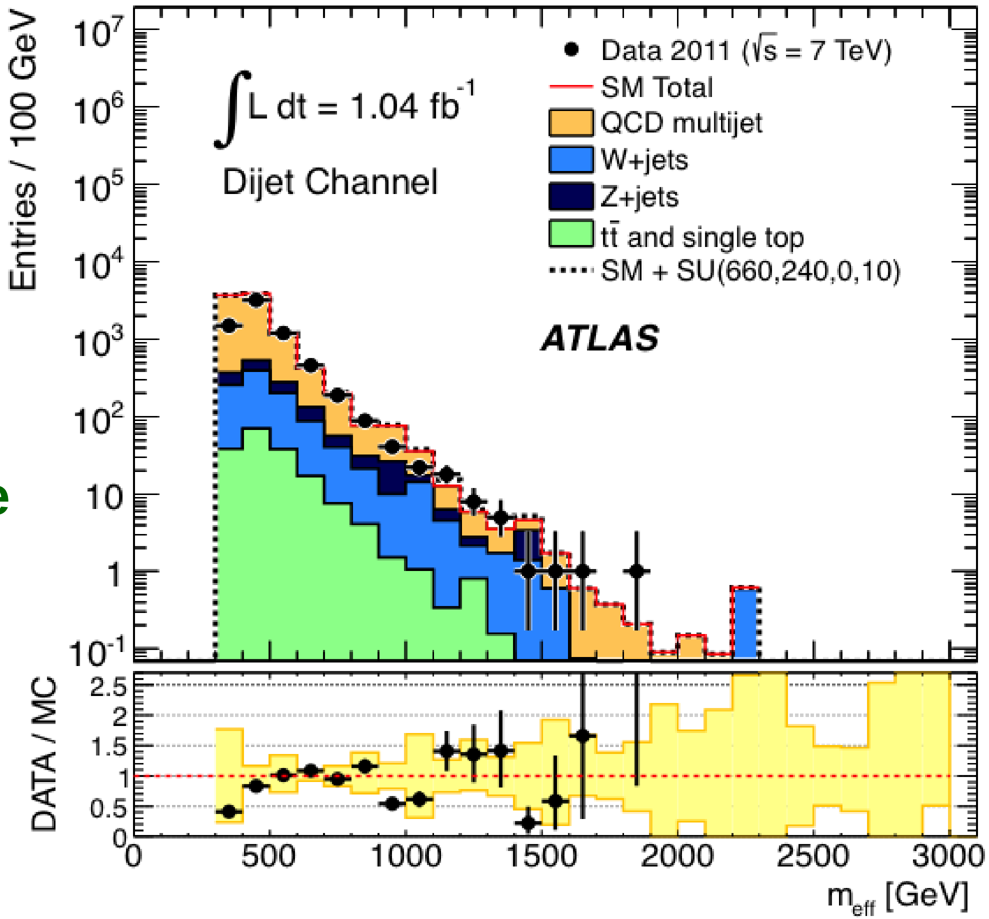
CR1b: Z+Jets Background

- **CR1b selects Z(→ee/μμ)+jets events and adds leptons to MET to model Z(→υυ)+jets**
- **SR MET/Meff, Δφ(j,MET) cuts and Meff cuts relaxed to increase acceptance (except for 4-jet M_{eff}>500 GeV SR)**
- **TF calculated using ALPGEN with theoretical and experimental systematics estimates**
- **Z(→ll)+jets SR background also taken into account in TF**
- **Both CR1a and CR1b constraints used in likelihood function**



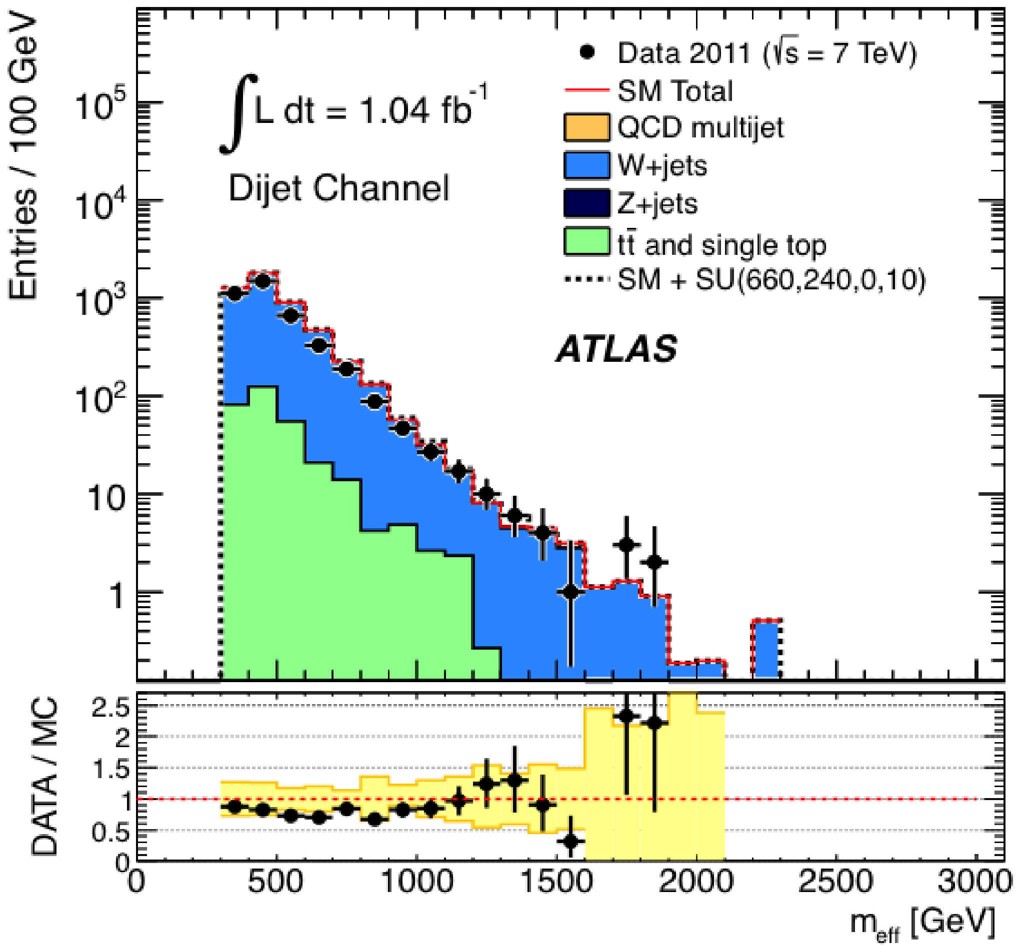
CR2: QCD Jet Background

- Require $\Delta\phi(j,MET)<0.2$ to create QCD jet dominated region
- TFs obtained by smearing p_T of jets in low MET 'seed' events using jet response function
- Jet response function baseline obtained from MC jet truth/reco comparison
- Gaussian part modified to match data jet p_T asymmetry distribution in dijet events
- Tail modified to match MET distribution in data 3-jet 'Mercedes' events



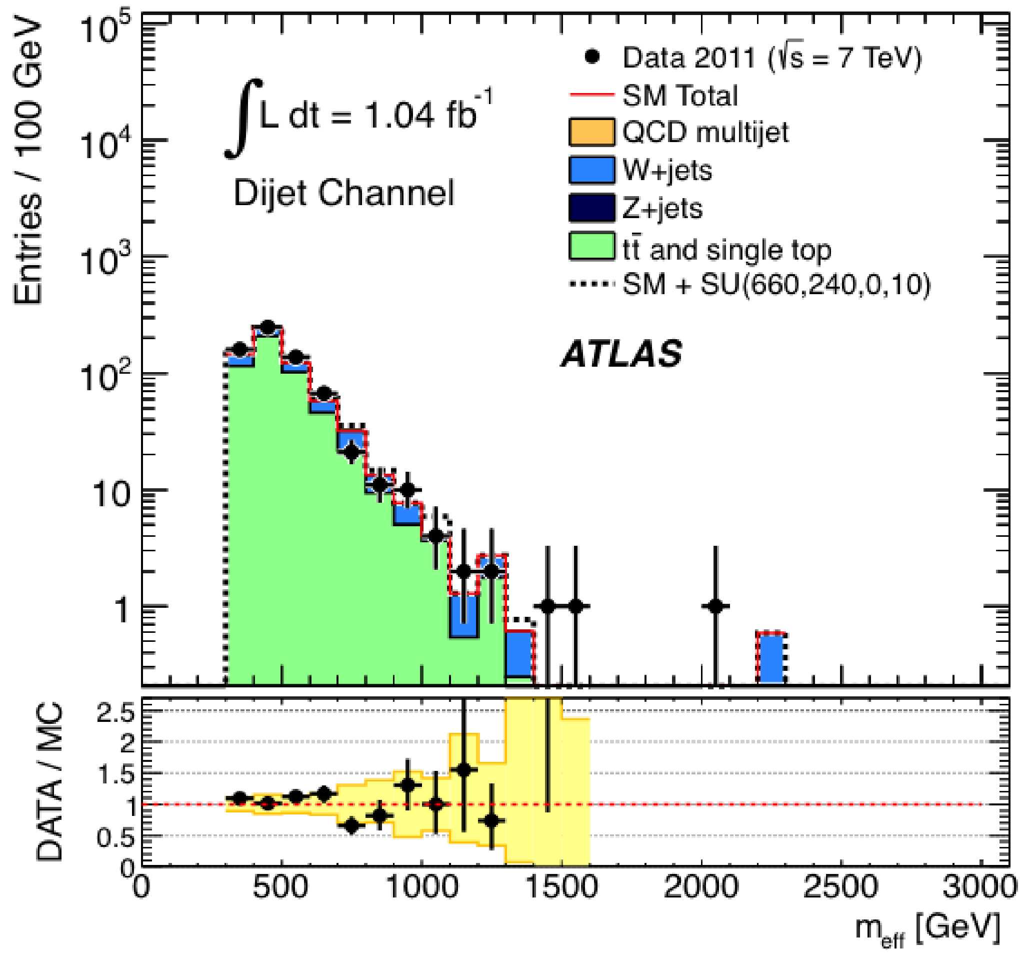
CR3: W+Jets Background

- **1-lepton + MET sample selected with 30 GeV<M_T(l,u) < 80 GeV requirement**
- **b-jet veto applied to separate from top control regions**
- **Lepton treated as jet (i.e. not added to MET): models approximately hadronictau faking jet**
- **TFs calculated using ALPGEN with theoretical and systematic uncertainties estimates**



CR4: Top Background

- 1-lepton + MET sample selected with 30 GeV<M_T(l,u) < 80 GeV requirement
- b-jet requirement applied to separate from W+jet control regions
- Lepton treated as jet (i.e. not added to MET): models approximately hadronictau faking jet
- TFs calculated using ALPGEN with theoretical and systematic uncertainties estimates



Transfer Factors

- **Example for ‘high mass’ signal region**

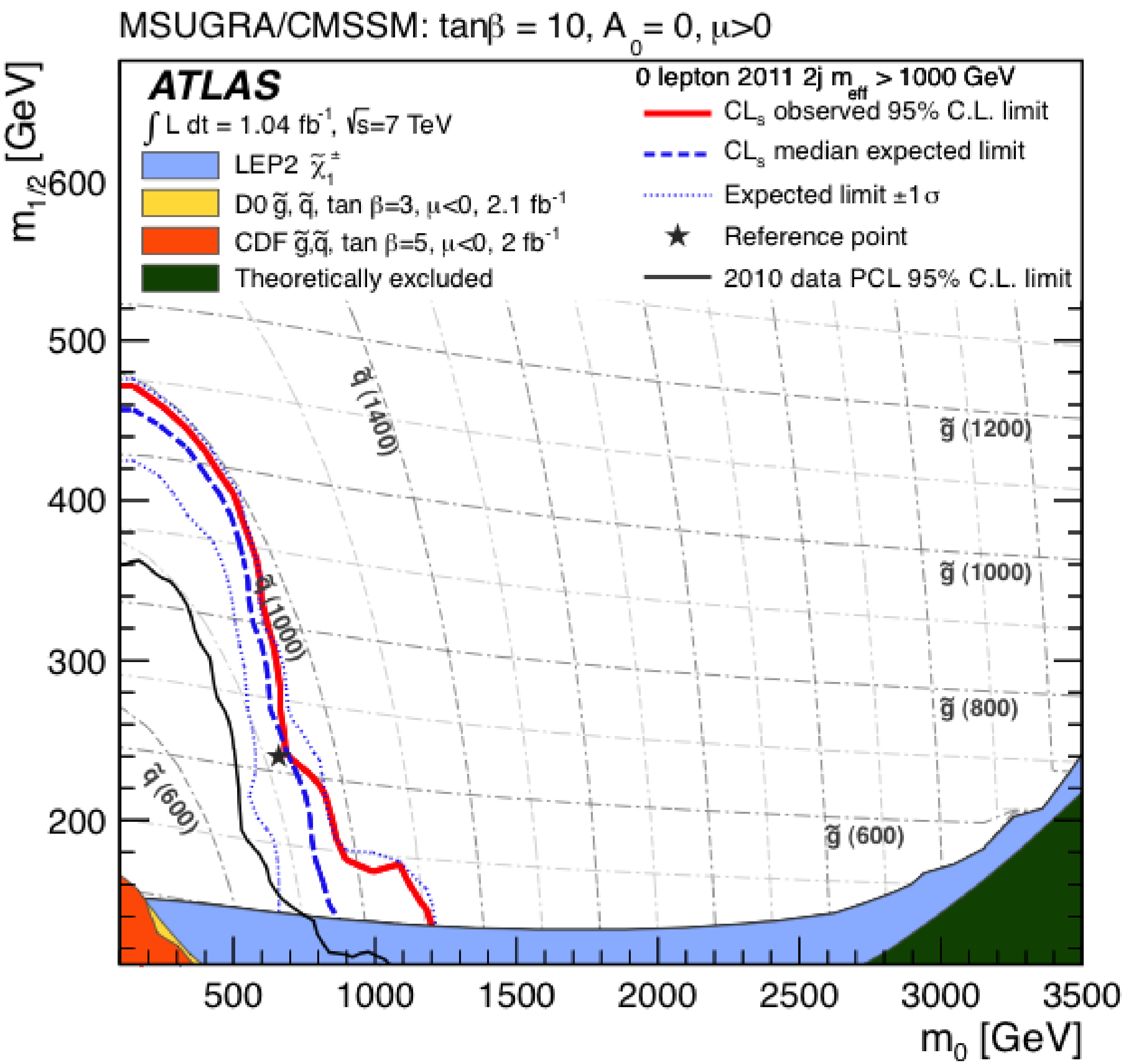
	Signal / Control Region					
	CR1a	CR1b	CR2	CR3	CR4	SR
Data	8	7	34	15	12	18
Targeted background	Z/γ+jets	Z/γ+jets	QCD multi-jet	W+jets	$t\bar{t}$ + single top	–
Transfer factor	0.374	0.812	0.063	0.196	0.372	–
Fitted Z/γ+jets	8.3	5.8	0.7	0.5	0.0	3.3
Fitted QCD multi-jet	–	–	29.8	0.8	0.6	2.1
Fitted W+jets	–	–	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

Results

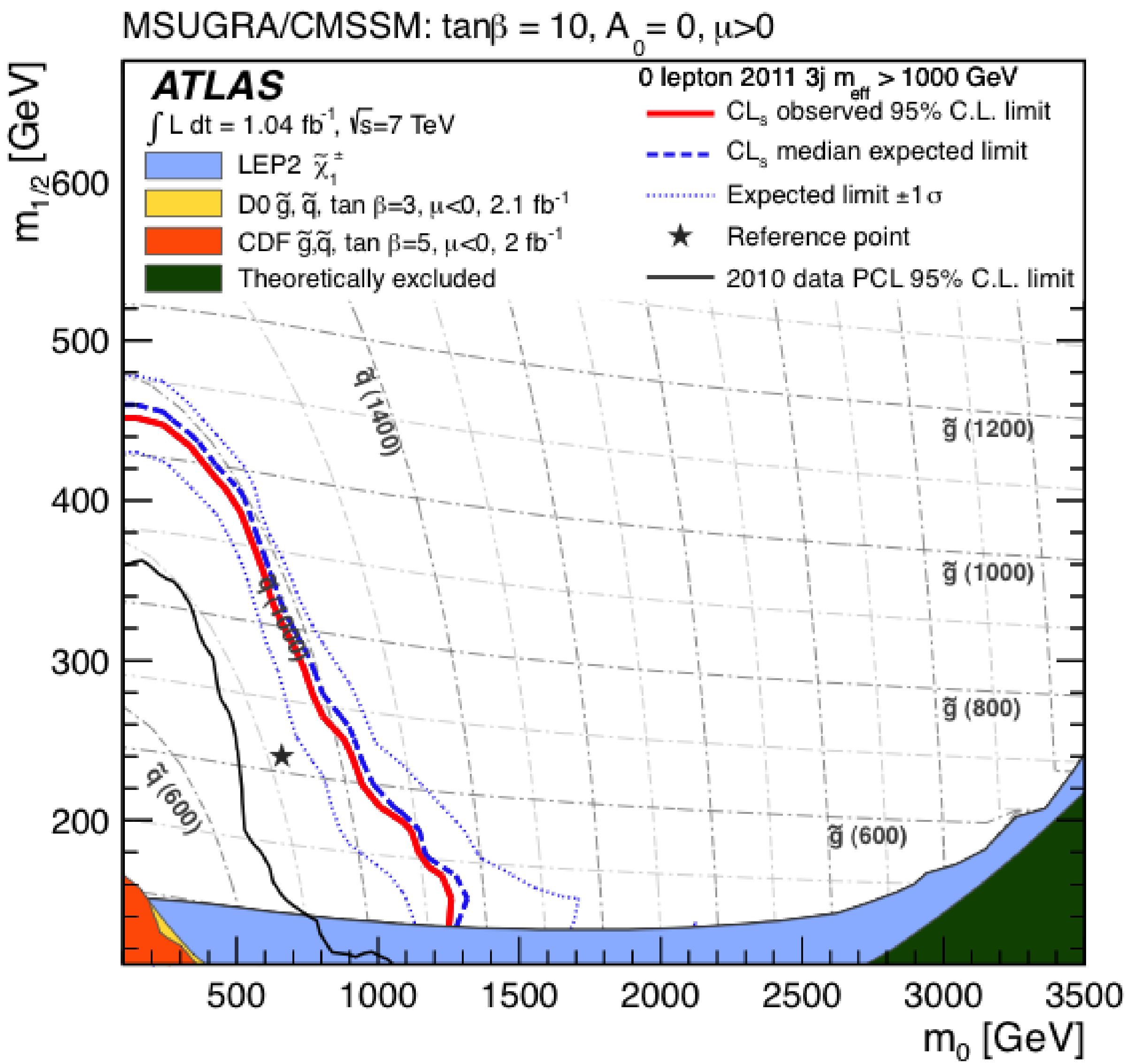
Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, $m_{\text{eff}} > 500$ GeV	≥ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ 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

- **No evidence of excess**
- **Set limits in model planes, taking into account background and signal systematics**

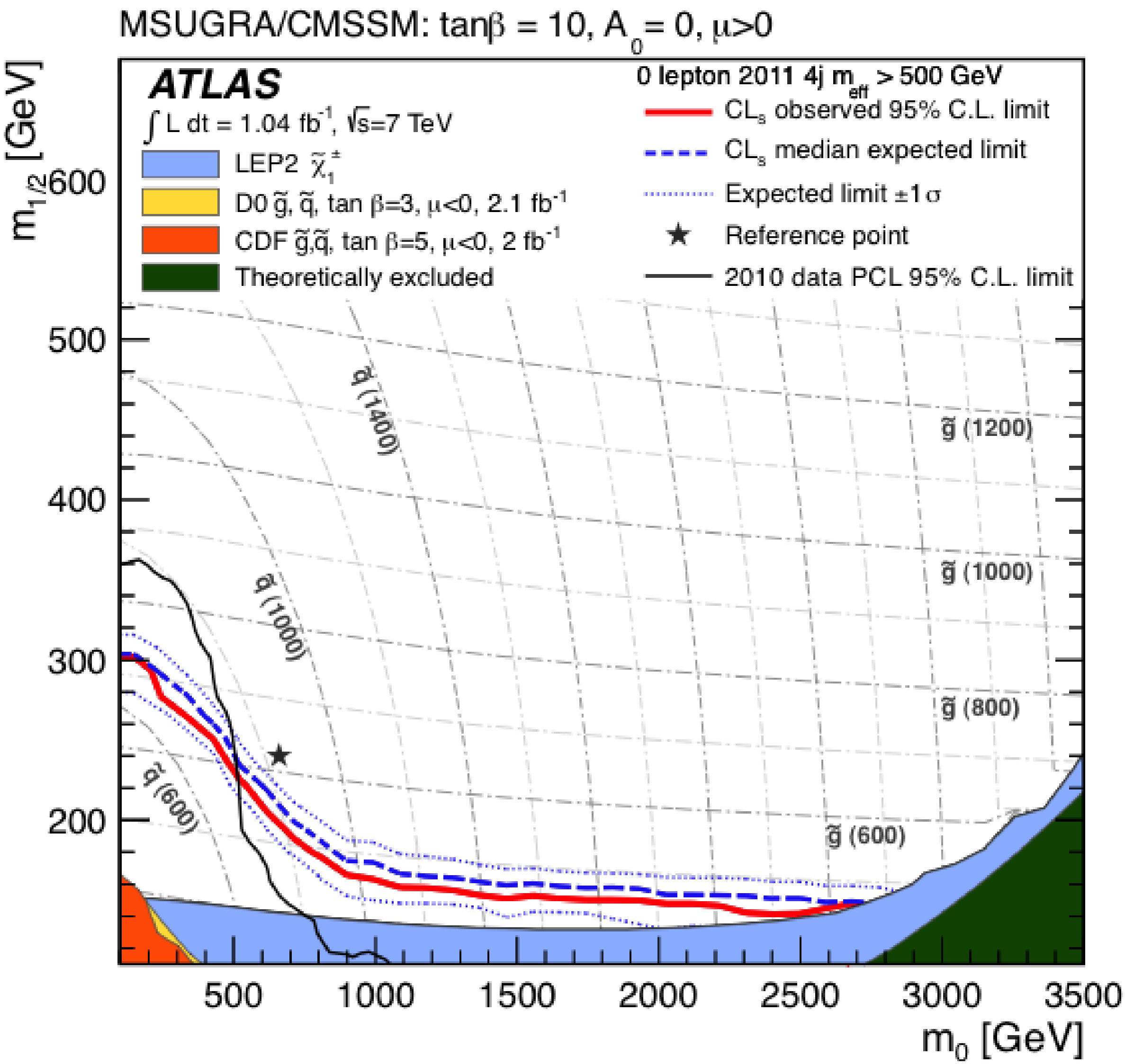
mSUGRA/CMSSM Limits



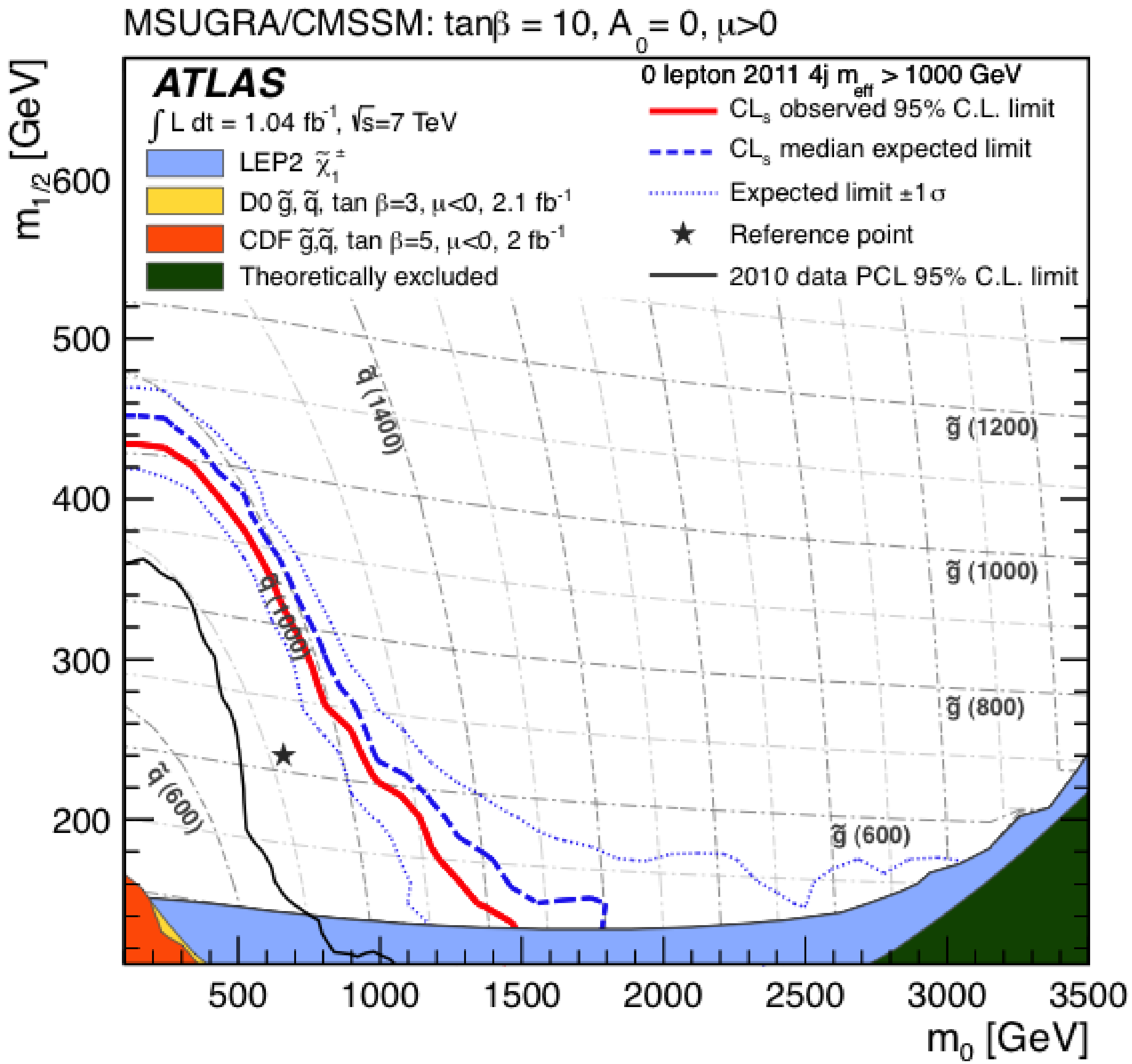
mSUGRA/CMSSM Limits



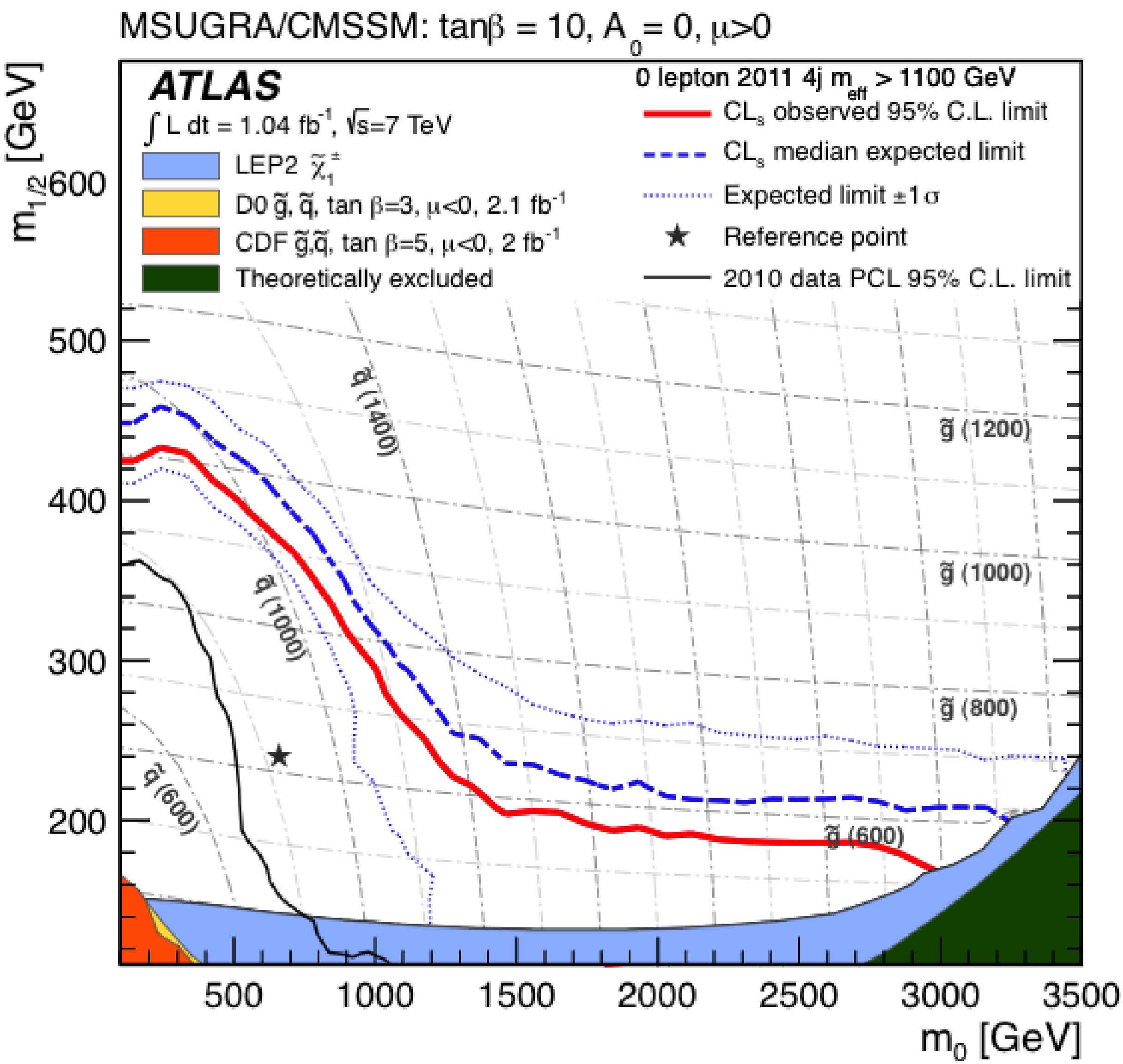
mSUGRA/CMSSM Limits



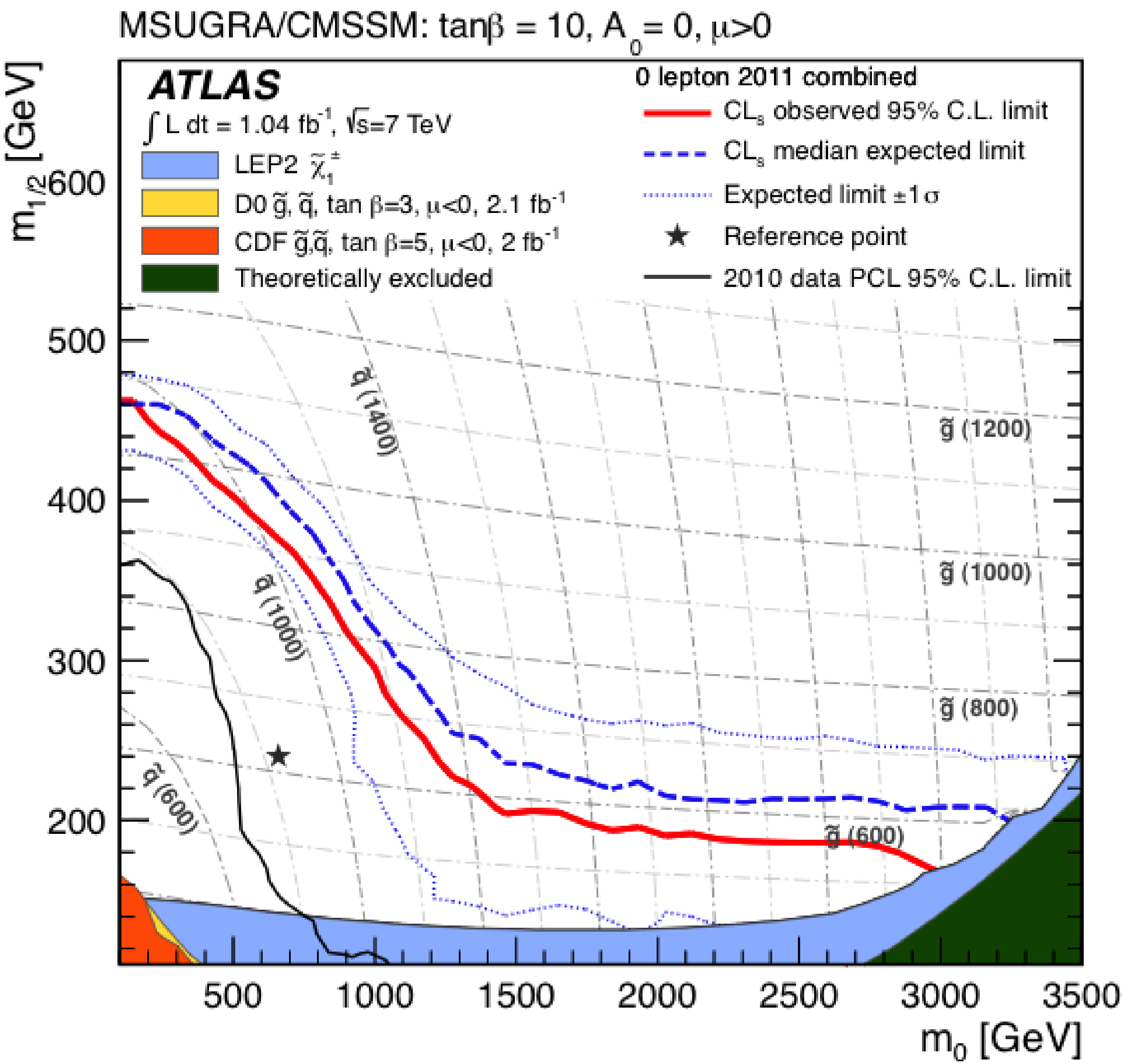
mSUGRA/CMSSM Limits



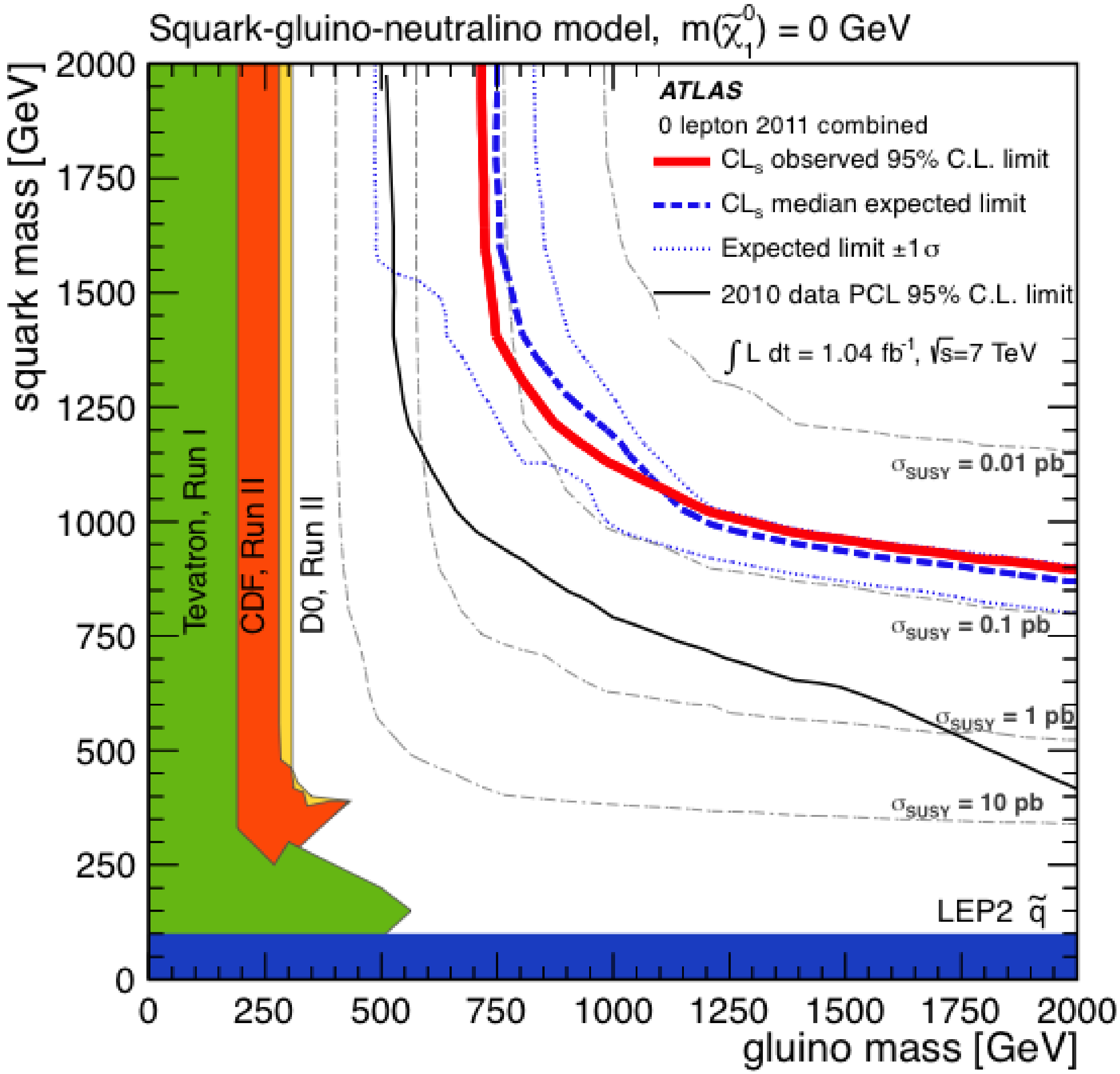
mSUGRA/CMSSM Limits



mSUGRA/CMSSM Limits



Simplified Model Limits



Cross-Section & Mass Limits

- Additional interpretation in terms of upper limits on $\sigma x \varepsilon x A$ for each channel
  - 22, 25, 429, 27 and 17 fb
- Alternative models can be checked by reproducing analysis applied to signal model
- Gluino (squark) masses below 700 (875) GeV excluded for squark (gluino) masses below 2 TeV and light LSP (m<200 GeV)
- Gluino/squark masses below 1075 GeV excluded for equal masses and light LSP(m<200 GeV)
- In mSUGRA / CMSSM degenerate mass limit ~ 950 GeV

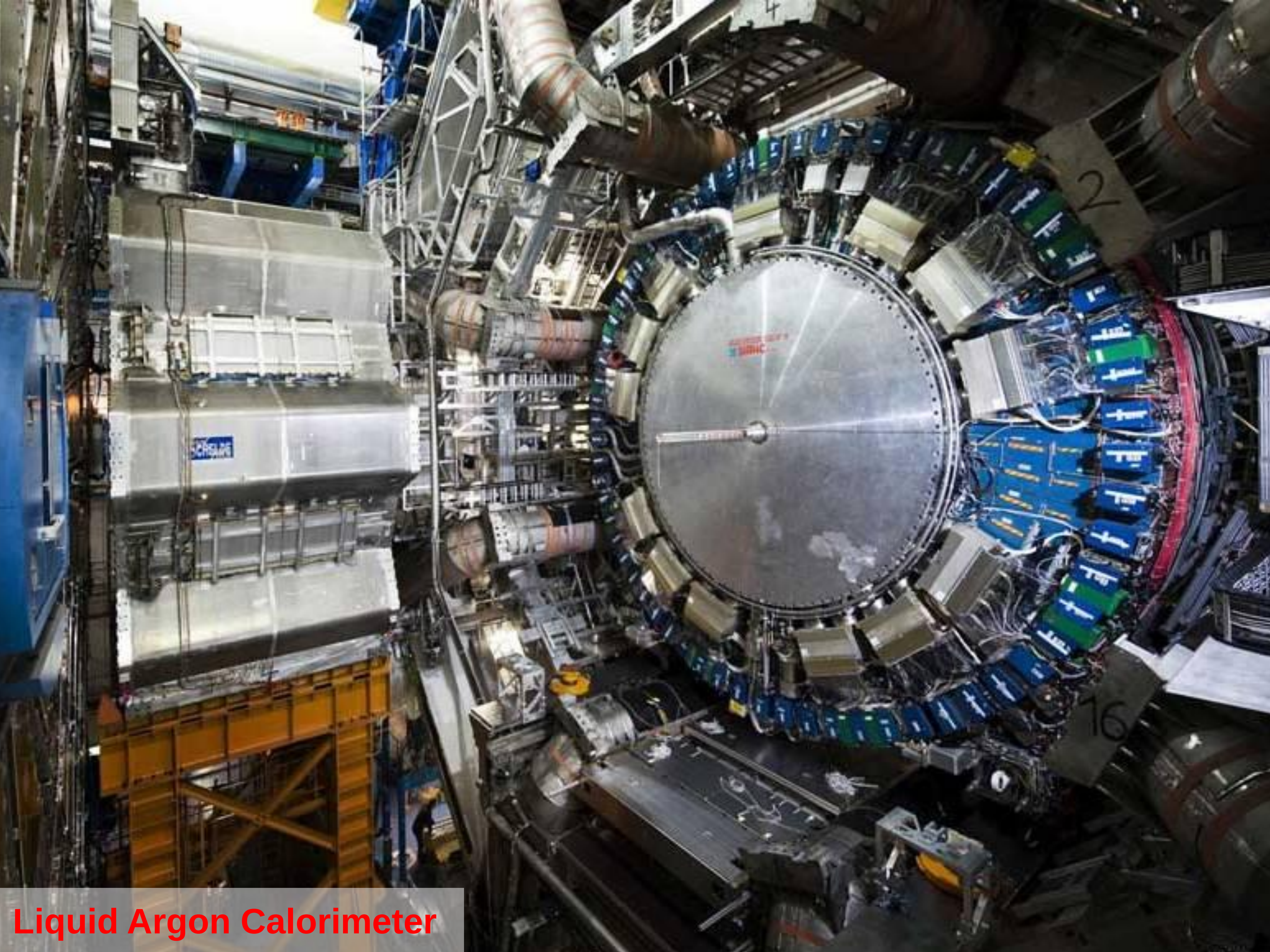
- **Dutta: “Discovering SUSY should not be a problem!”**

Back-up

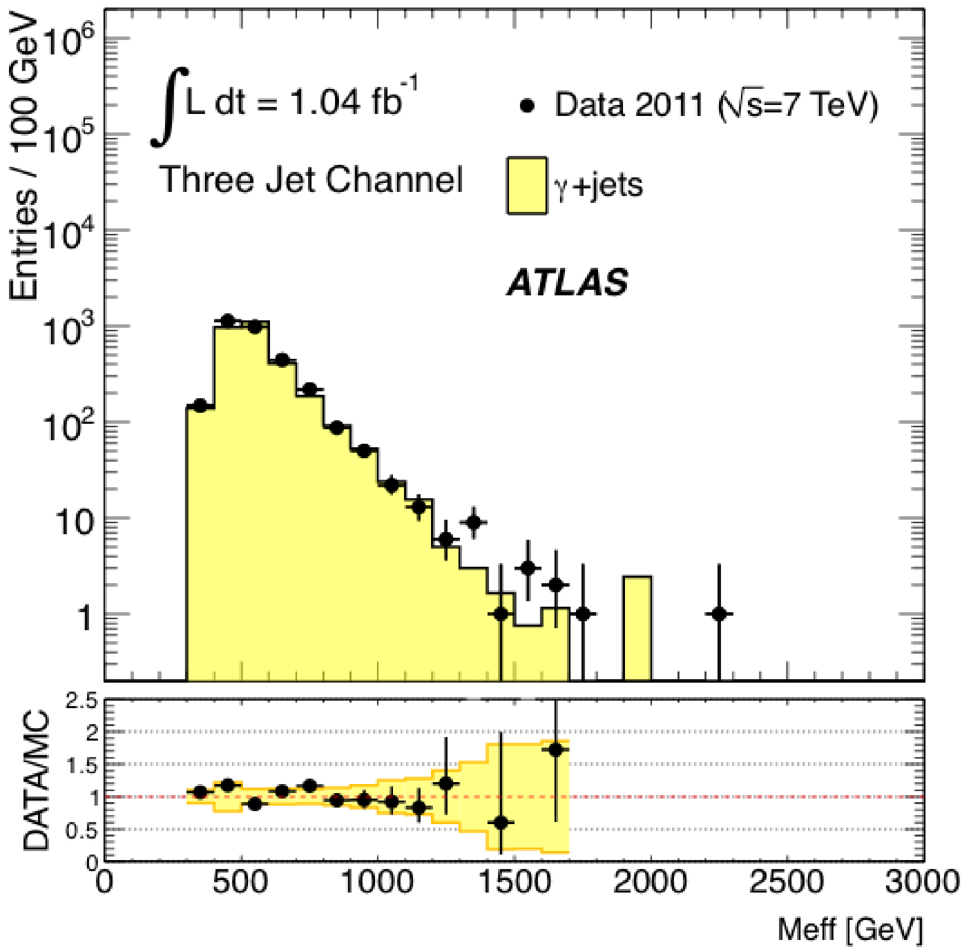
ATLAS Collaboration

>3000 physicists
38 countries
175 institutes

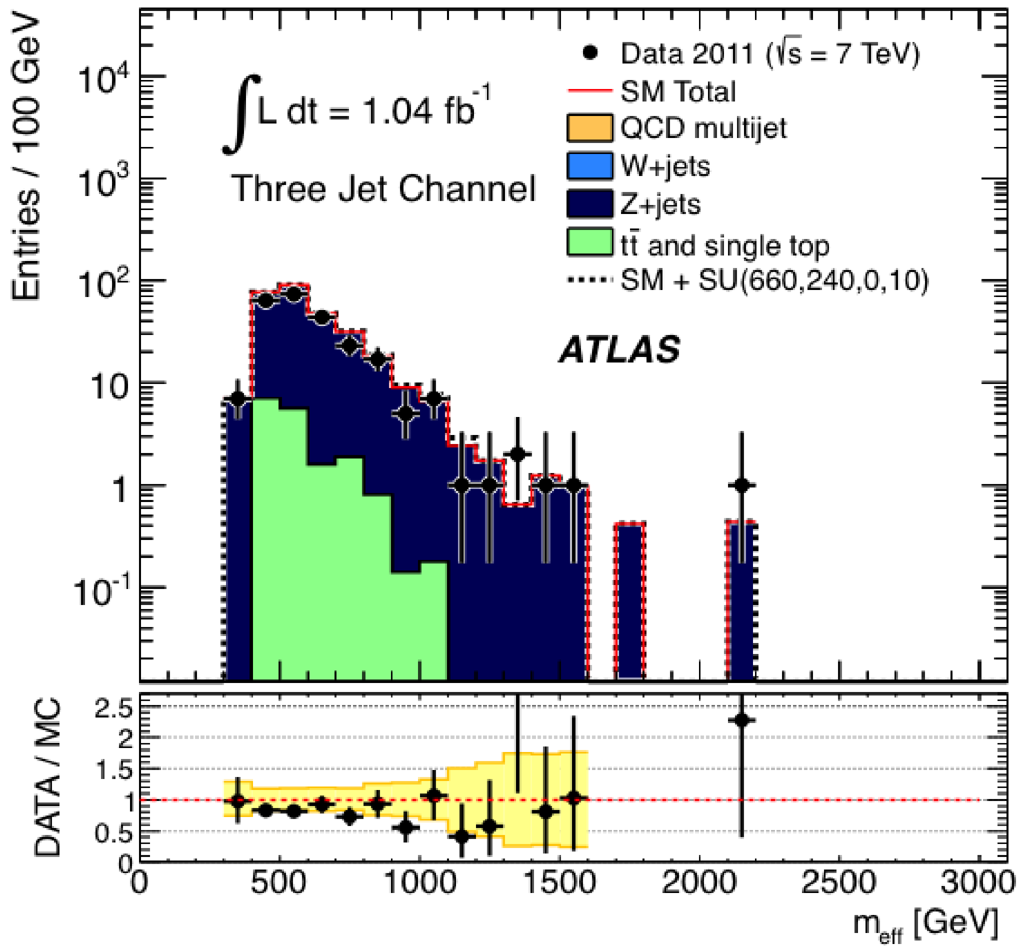
~300 UK
14 institutes



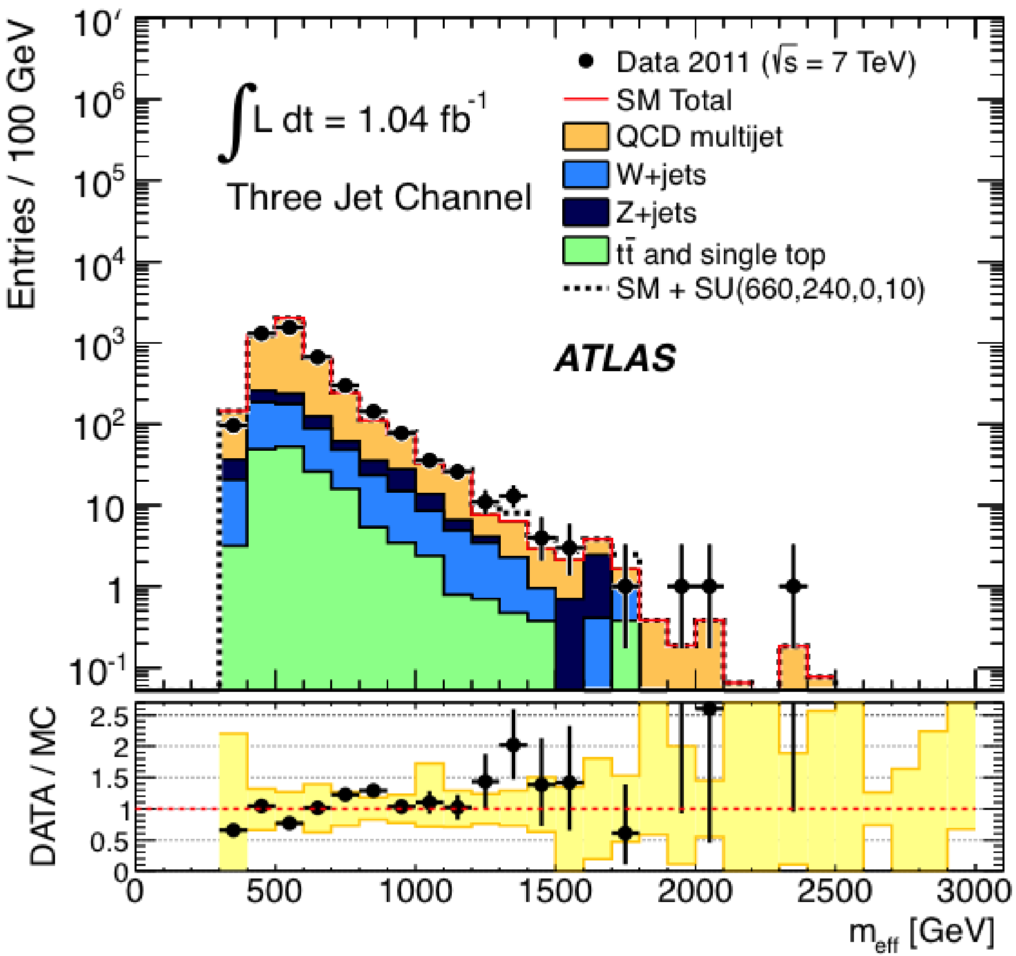
Liquid Argon Calorimeter



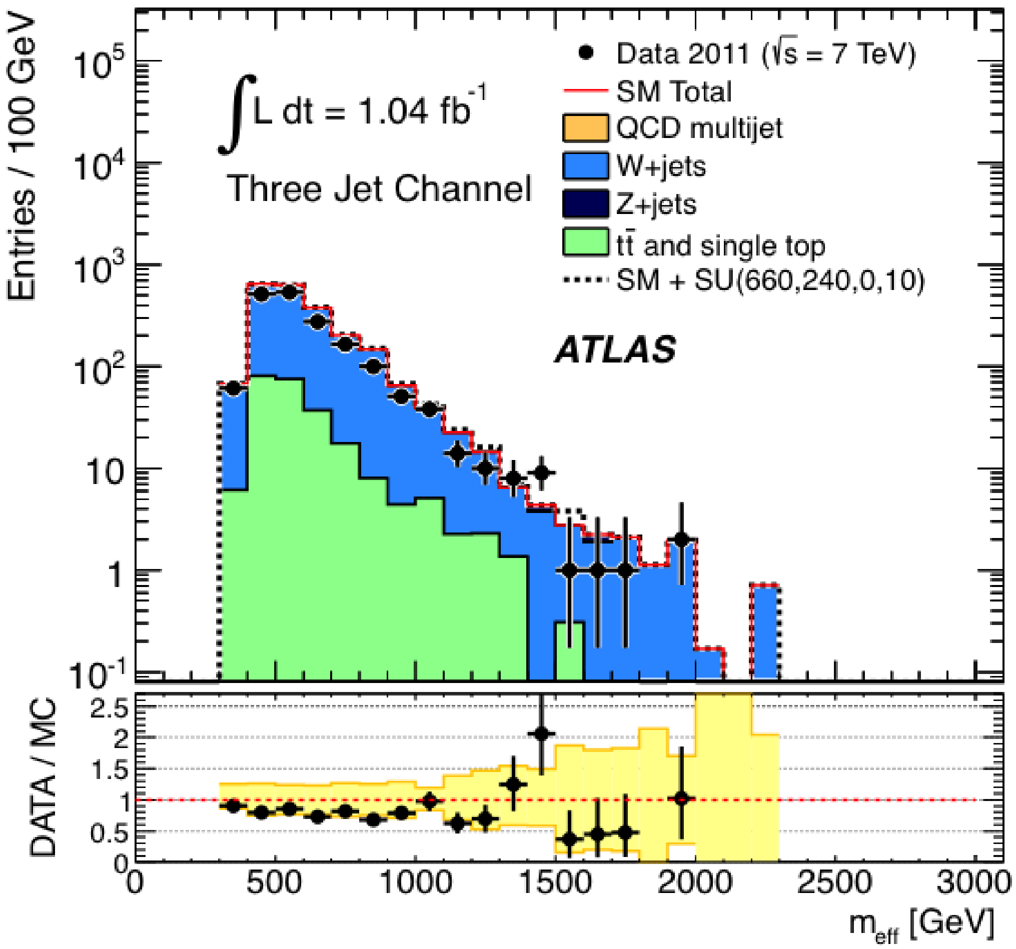
Entries / 100 GeV
$\int$L dt = 1.04 fb^{-1}
Three Jet Channel
Data 2011 ($\sqrt{s}$=7 TeV)
γ+jets
ATLAS
DATA/MC
Meff [GeV]

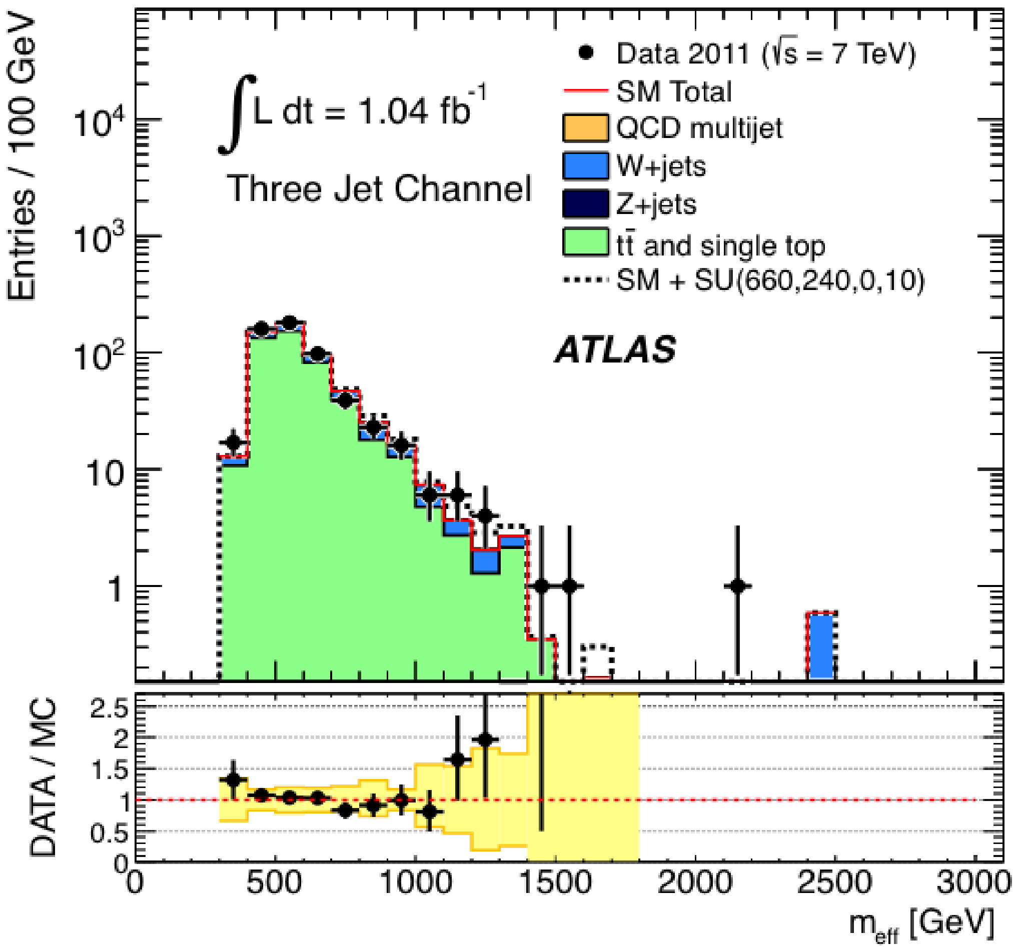


Data 2011 (√s = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
tt̄ and single top
SM + SU(660,240,0,10)
∫L dt = 1.04 fb-1
Three Jet Channel
ATLAS
Entries / 100 GeV
DATA / MC
meff [GeV]

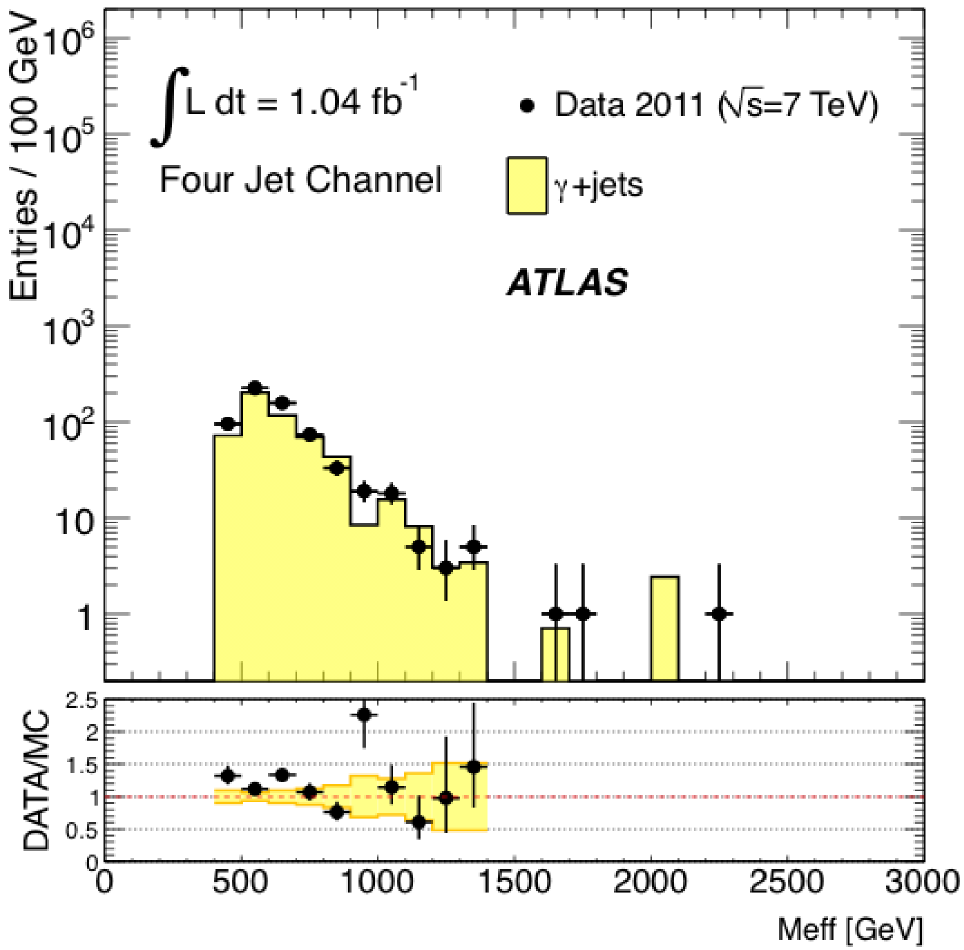


Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Three Jet Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_{eff} [GeV]

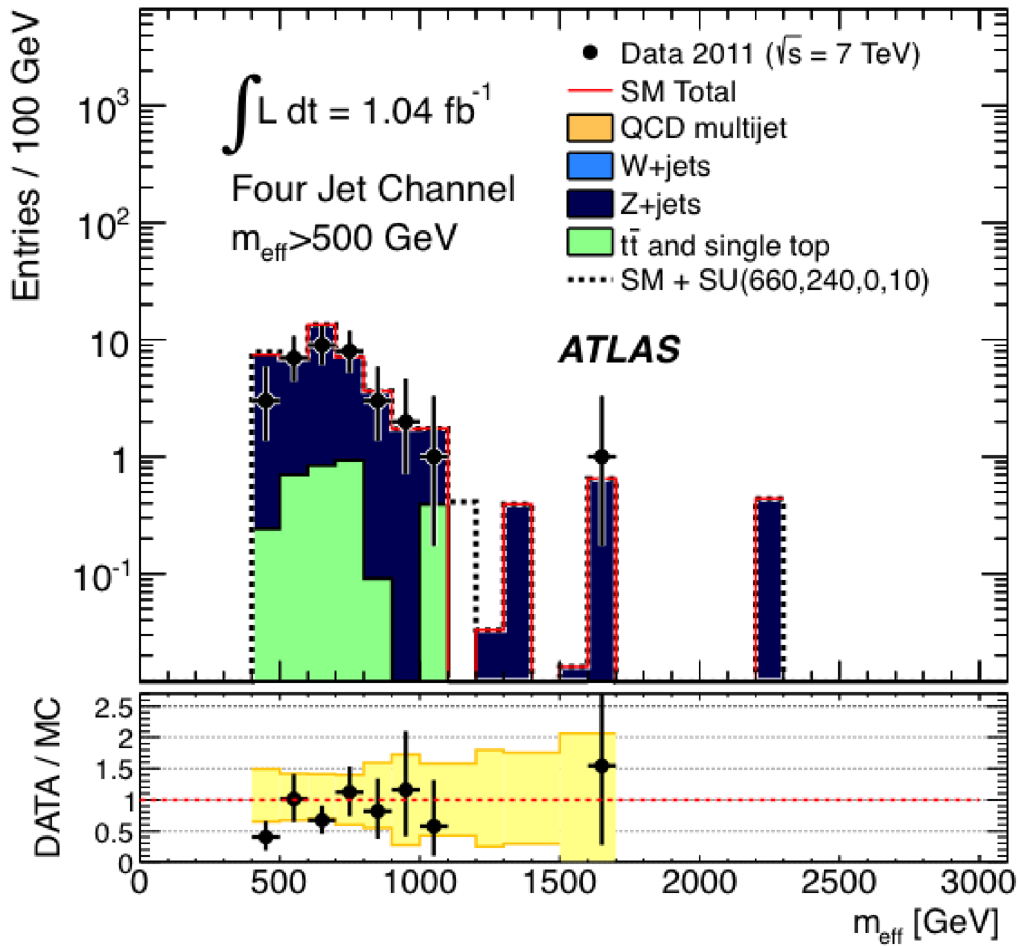

Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Three Jet Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_{eff} [GeV]

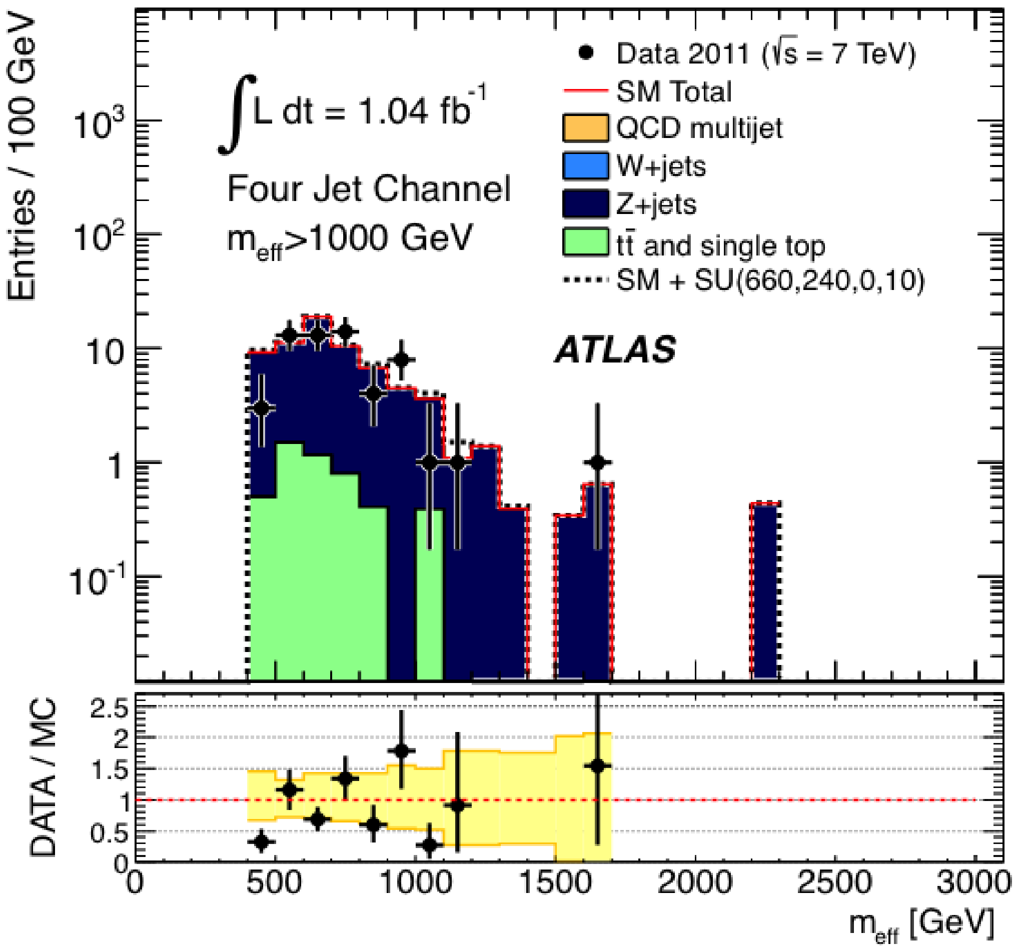


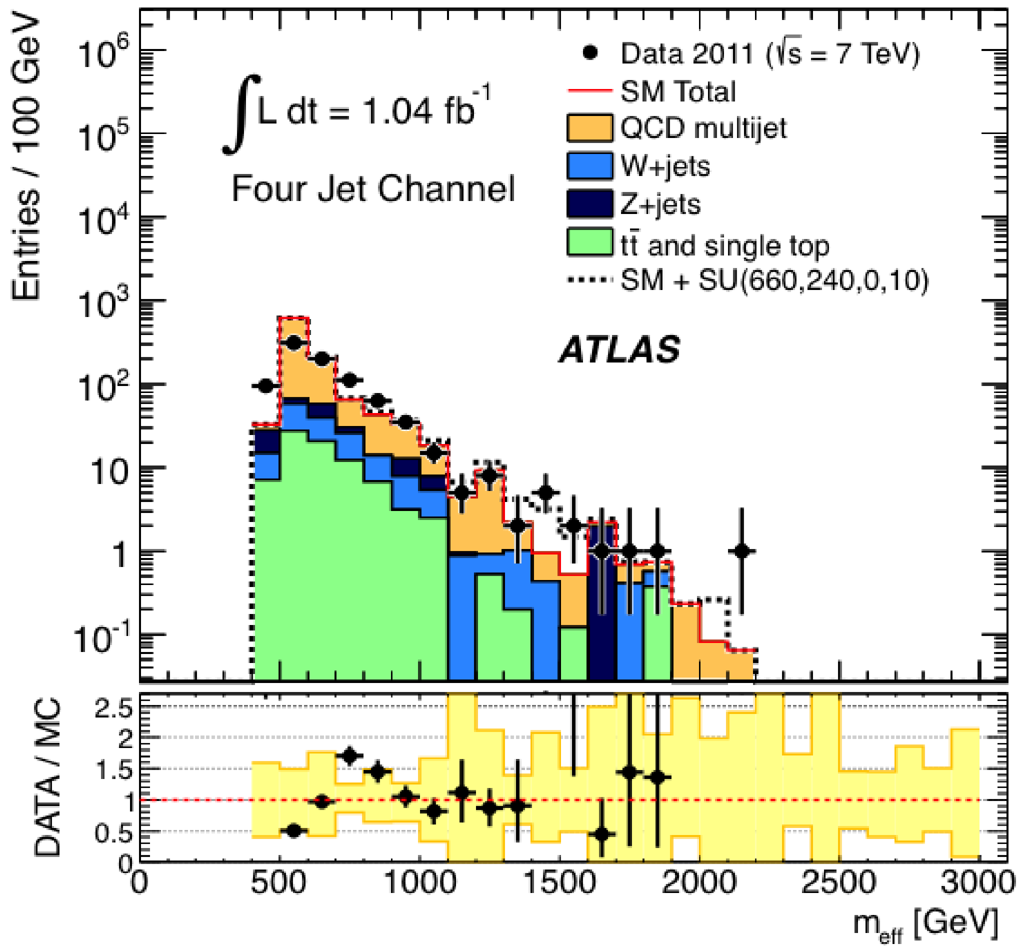
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
$\int L\, dt = 1.04\ fb^{-1}$
Three Jet Channel
ATLAS
Entries / 100 GeV
DATA / MC
m_{eff} [GeV]



Entries / 100 GeV
10^6
10^5
10^4
10^3
10^2
10
1
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet Channel
Data 2011 ($\sqrt{s}$=7 TeV)
γ+jets
ATLAS
DATA/MC
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
Meff [GeV]


Entries / 100 GeV
$\int L\, dt = 1.04\ fb^{-1}$
Four Jet Channel
m_{eff}>500 GeV
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
10^3
10^2
10
1
10^{-1}
DATA / MC
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
m_{eff} [GeV]


Entries / 100 GeV
∫L dt = 1.04 fb^-1
Four Jet Channel
m_eff>1000 GeV
Data 2011 (√s = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
tt̄ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_eff [GeV]


Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
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$t\bar{t}$ and single top
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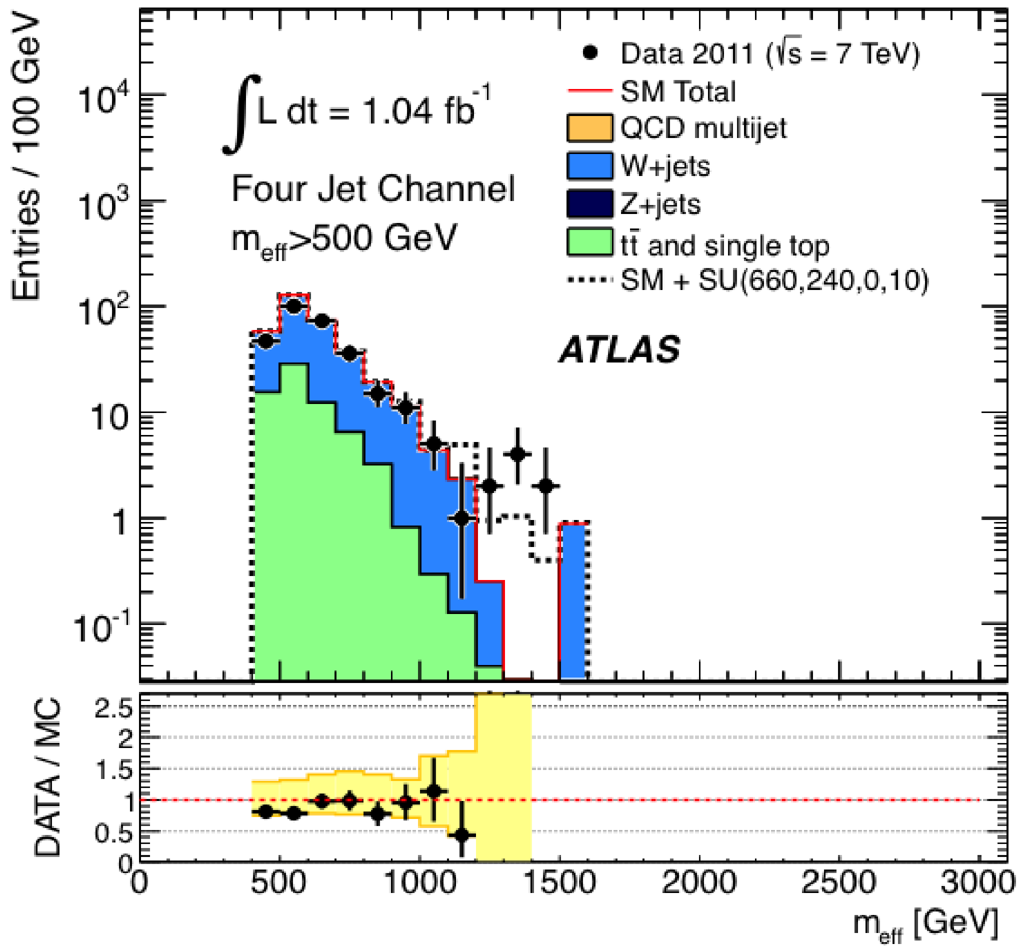
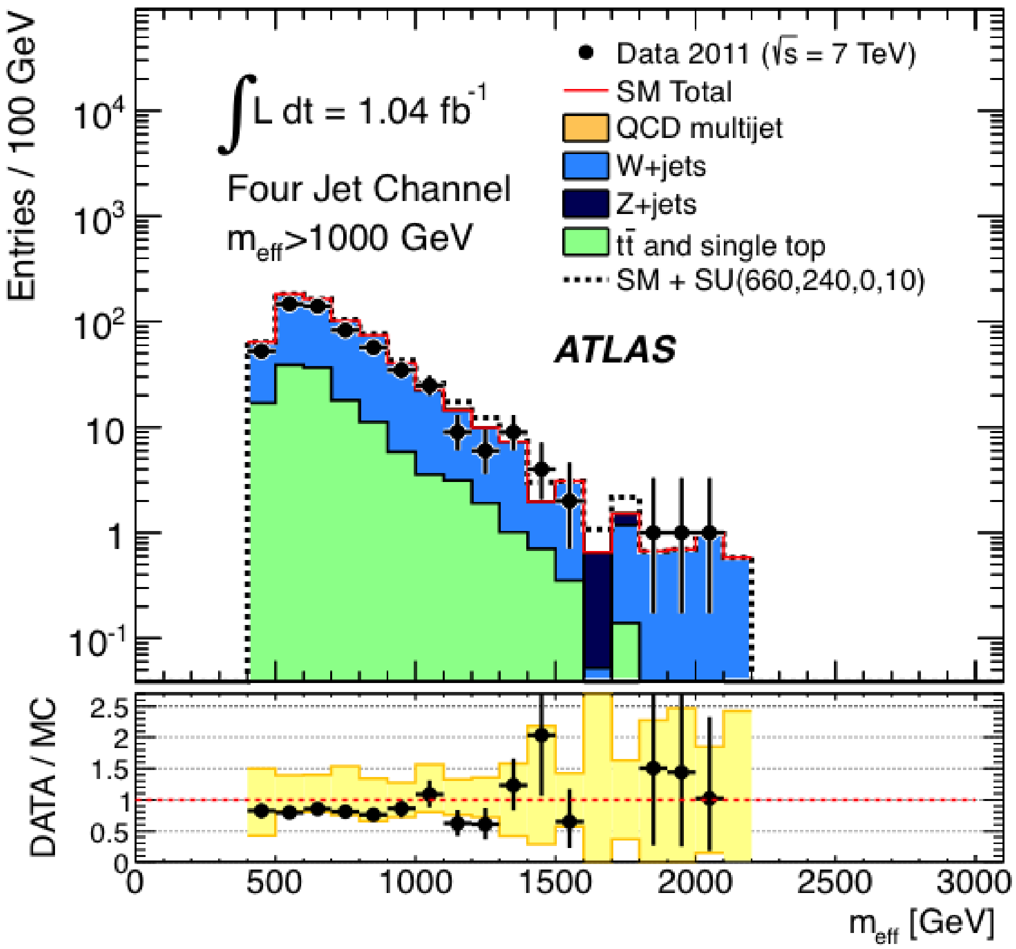
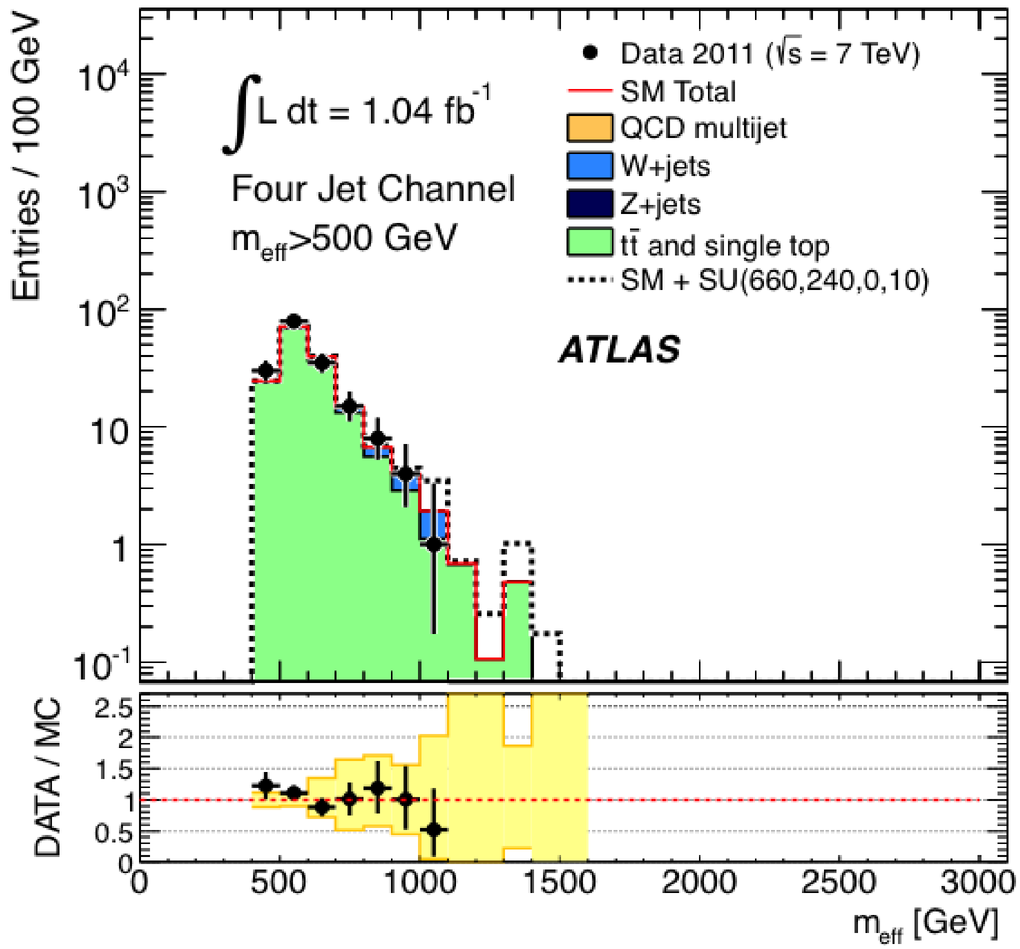
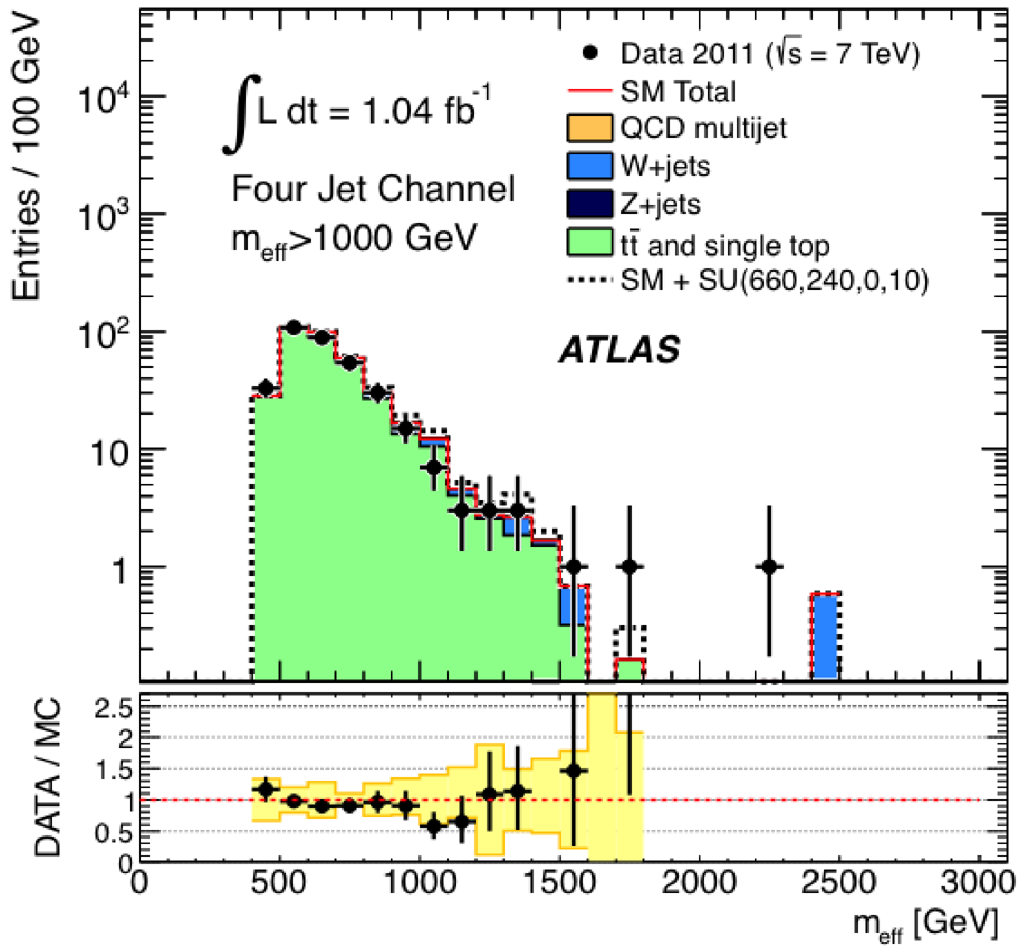
ATLAS
DATA / MC
m_{eff} [GeV]


Entries / 100 GeV
$\int L\, dt = 1.04\ fb^{-1}$
Four Jet Channel
m_{eff}>500 GeV
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
10^4
10^3
10^2
10
1
10^{-1}
DATA / MC
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
m_{eff} [GeV]

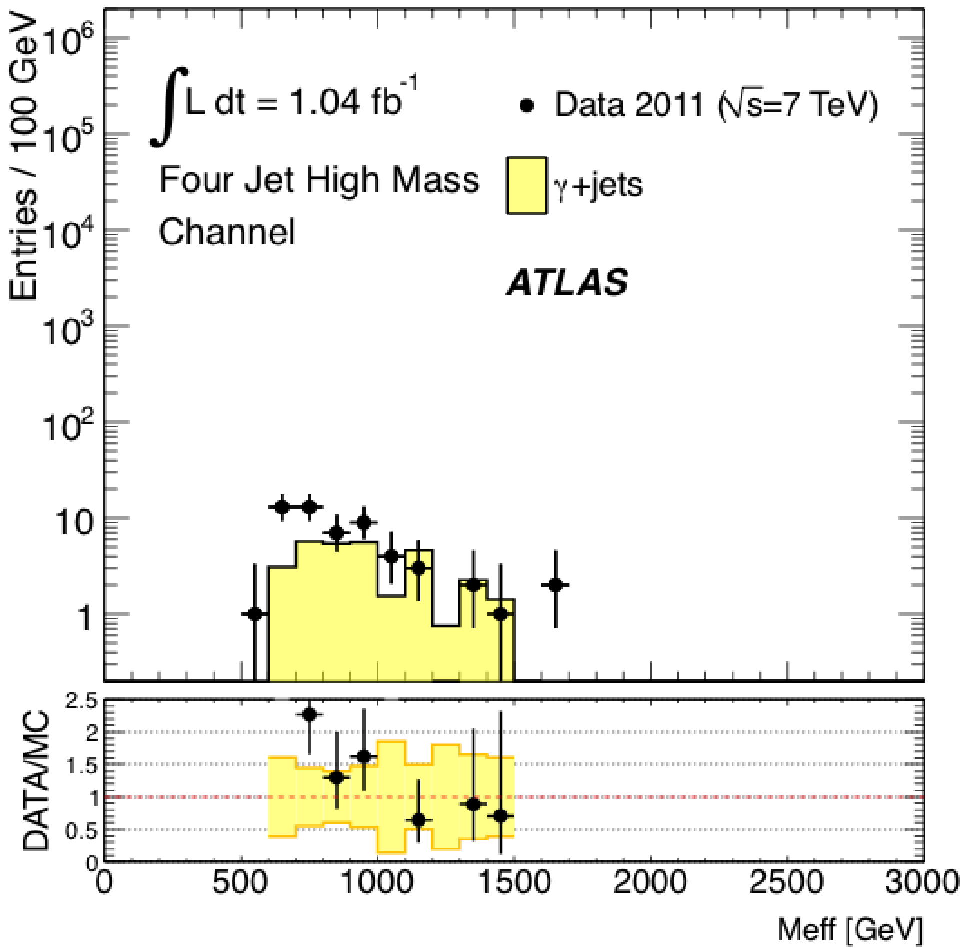

Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet Channel
m_{eff}>1000 GeV
ATLAS
Entries / 100 GeV
DATA / MC
m_{eff} [GeV]



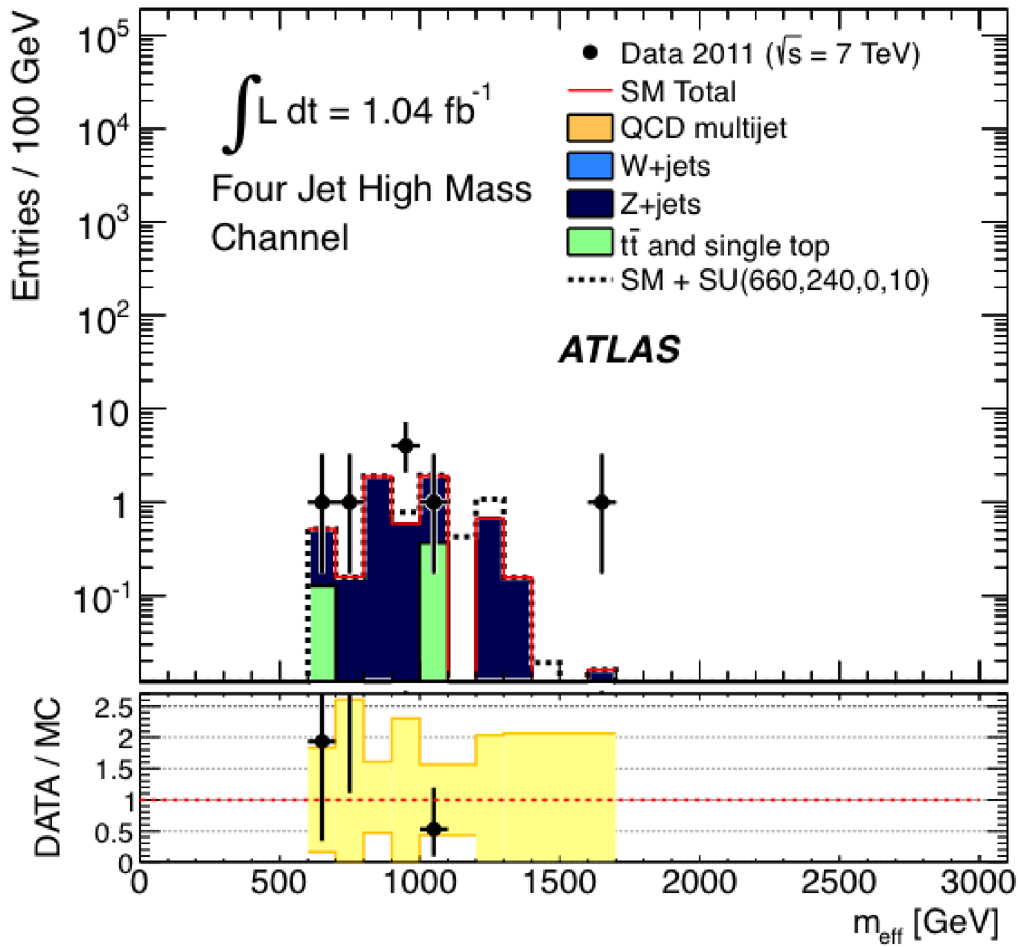
Entries / 100 GeV
∫L dt = 1.04 fb-1
Four Jet Channel
meff>500 GeV
Data 2011 (√s = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
tt̄ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
meff [GeV]



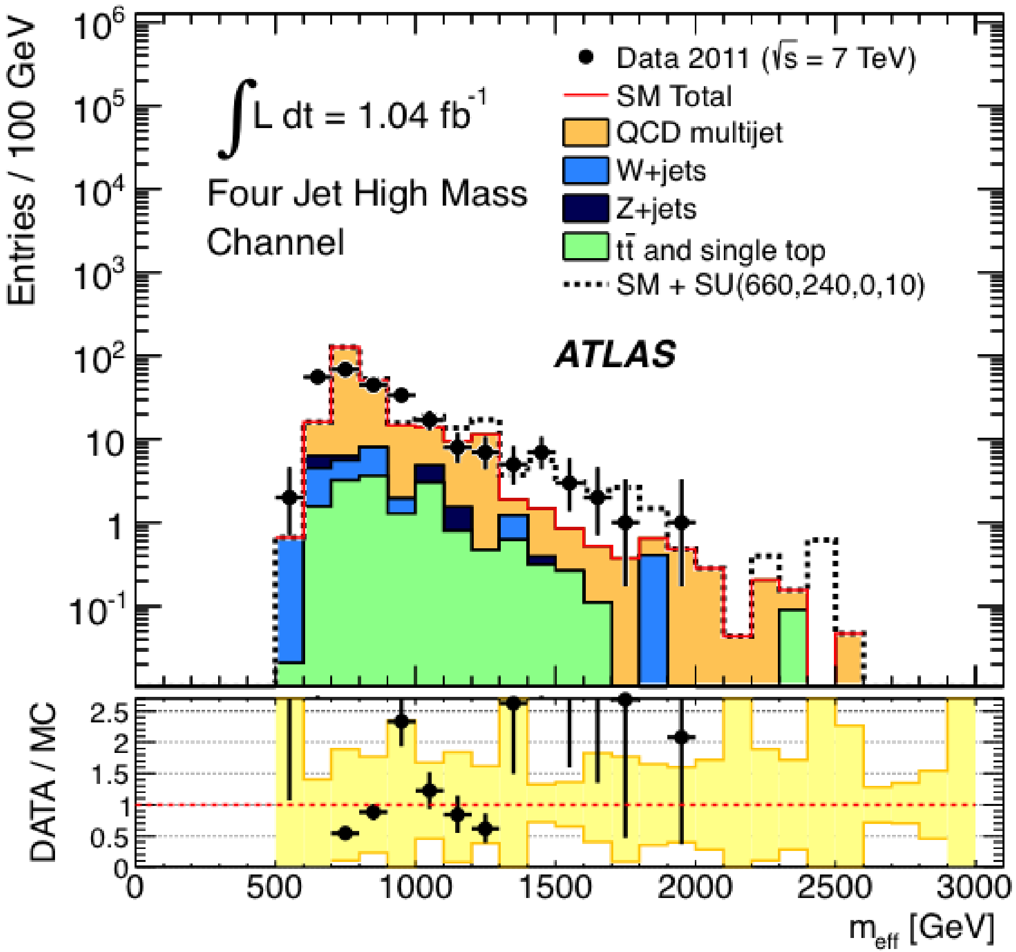
Entries / 100 GeV
∫L dt = 1.04 fb-1
Four Jet Channel
meff>1000 GeV
Data 2011 (√s = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
tt̄ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
meff [GeV]



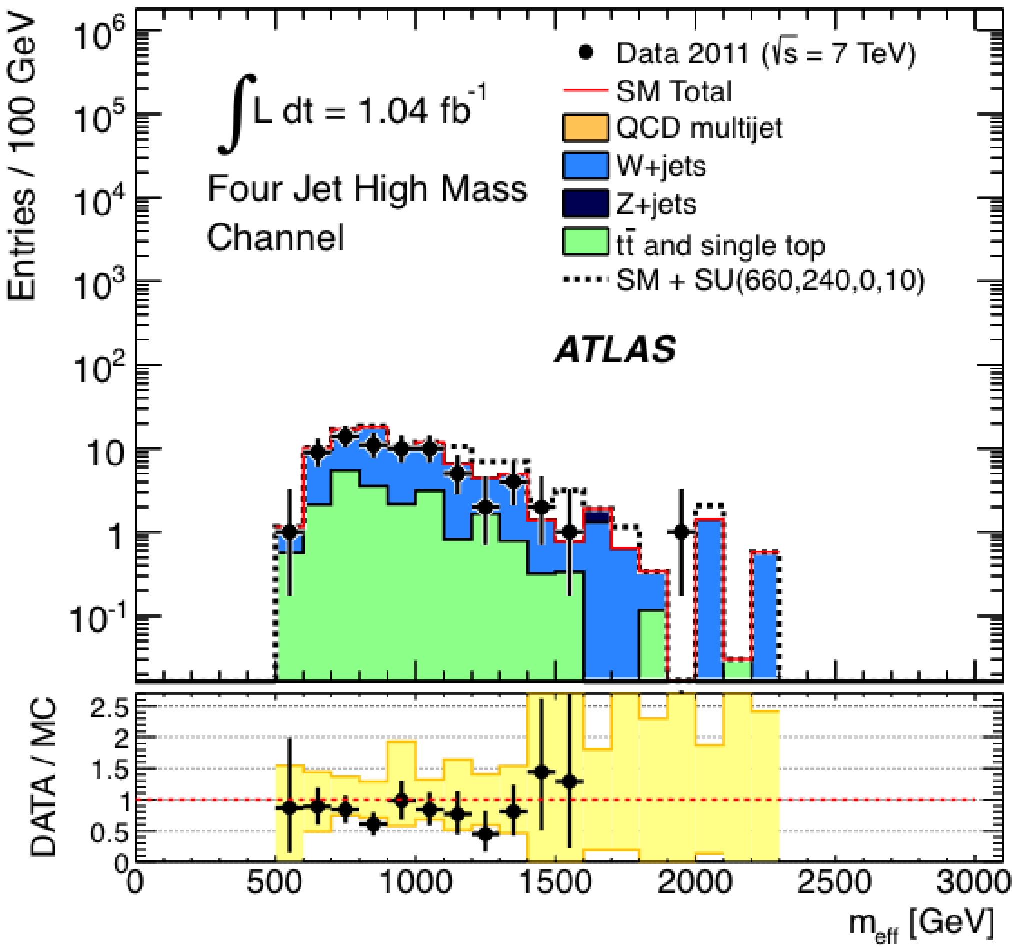
Entries / 100 GeV
10^6
10^5
10^4
10^3
10^2
10
1
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet High Mass
Channel
Data 2011 ($\sqrt{s}$=7 TeV)
γ+jets
ATLAS
DATA/MC
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
3000
Meff [GeV]



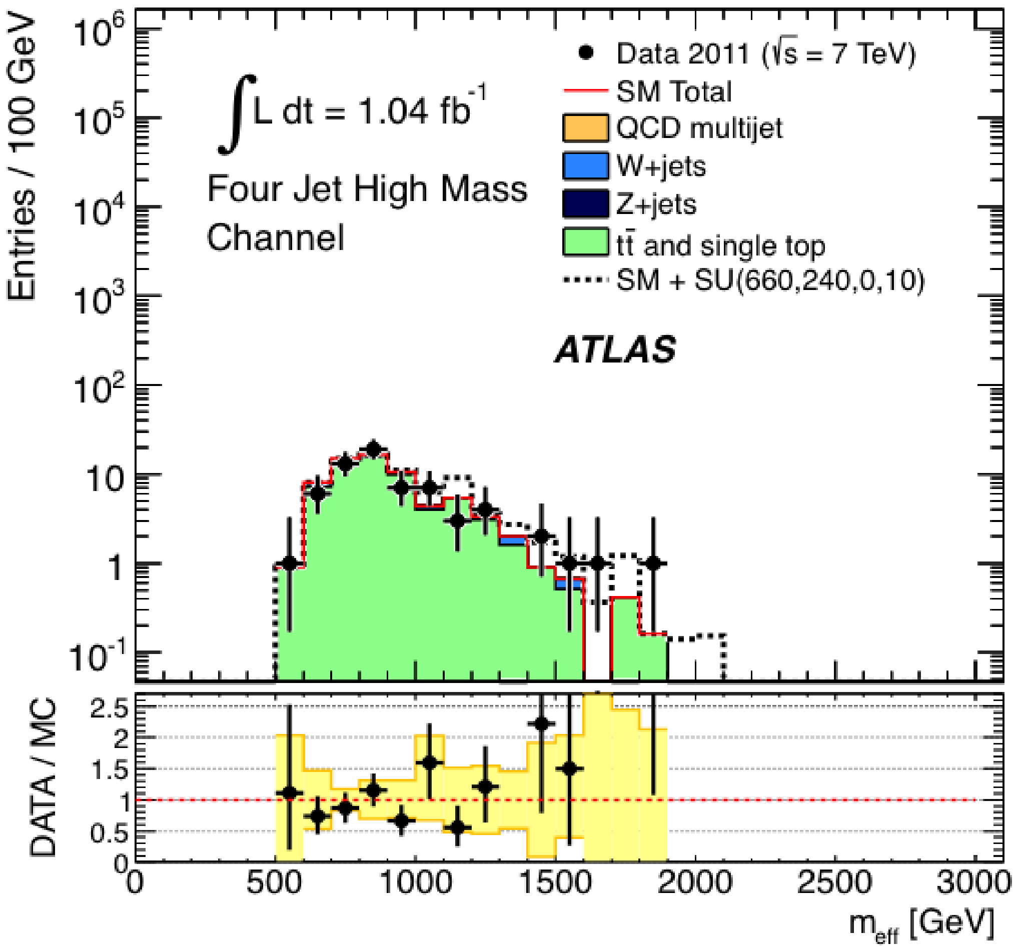
Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet High Mass
Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_{eff} [GeV]

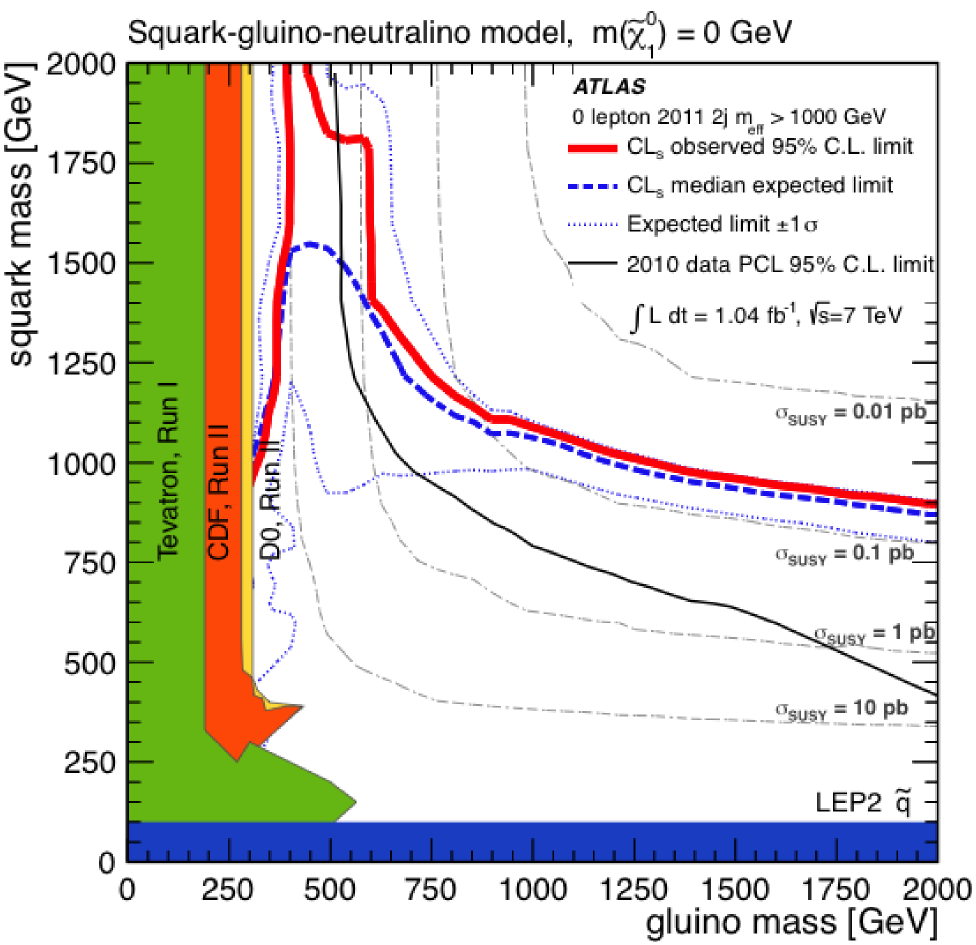


Entries / 100 GeV
∫L dt = 1.04 fb^-1
Four Jet High Mass Channel
Data 2011 (√s = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
tt̄ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_eff [GeV]

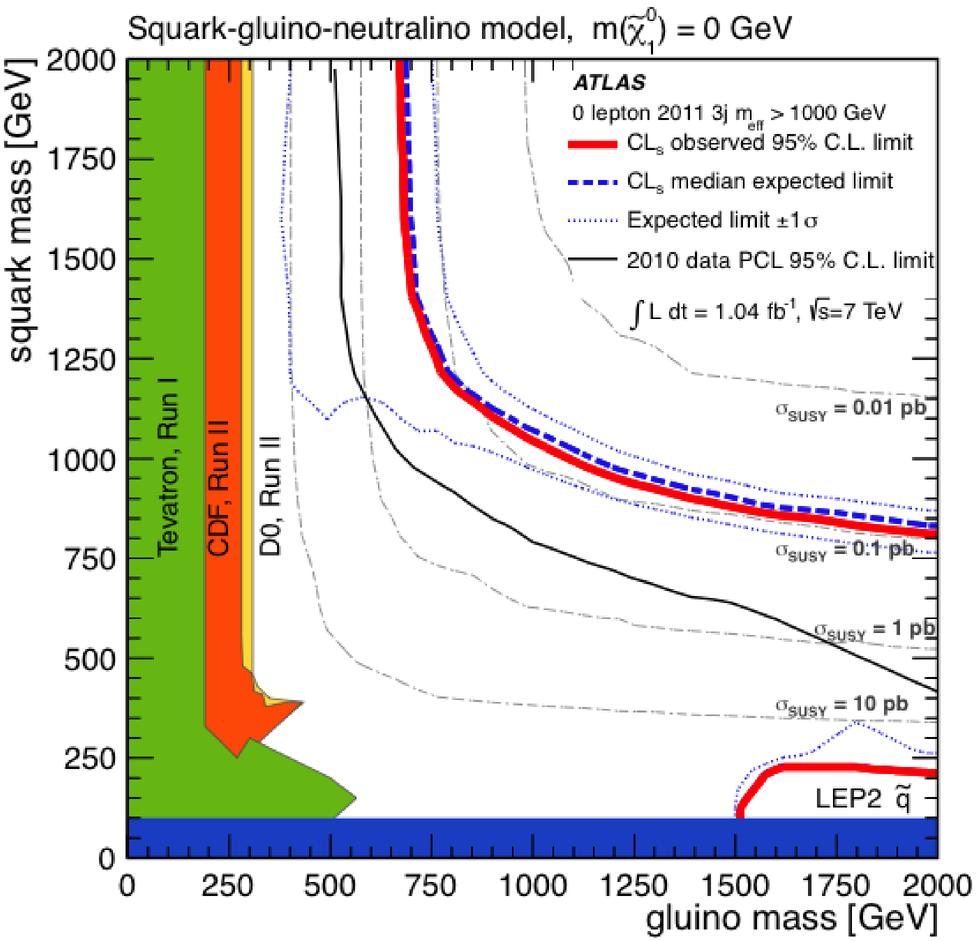


Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet High Mass Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_{eff} [GeV]

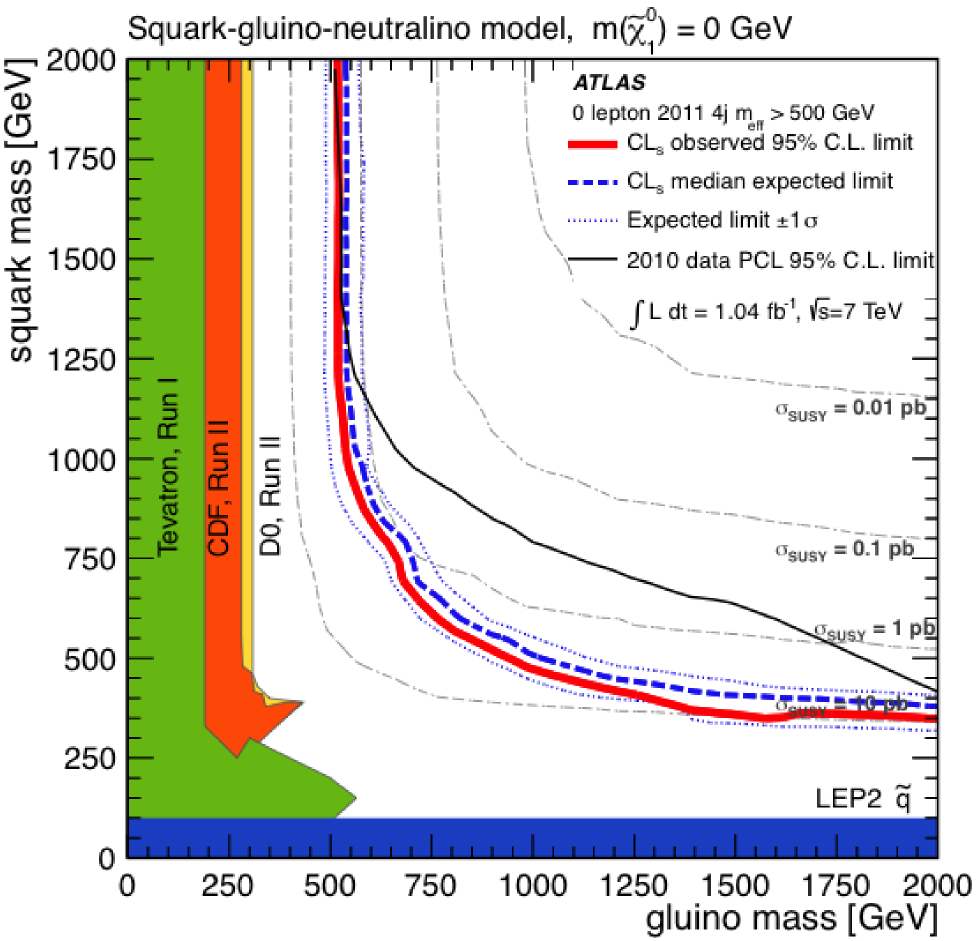

Entries / 100 GeV
$\int L\,dt = 1.04\ fb^{-1}$
Four Jet High Mass Channel
Data 2011 ($\sqrt{s}$ = 7 TeV)
SM Total
QCD multijet
W+jets
Z+jets
$t\bar{t}$ and single top
SM + SU(660,240,0,10)
ATLAS
DATA / MC
m_{eff} [GeV]



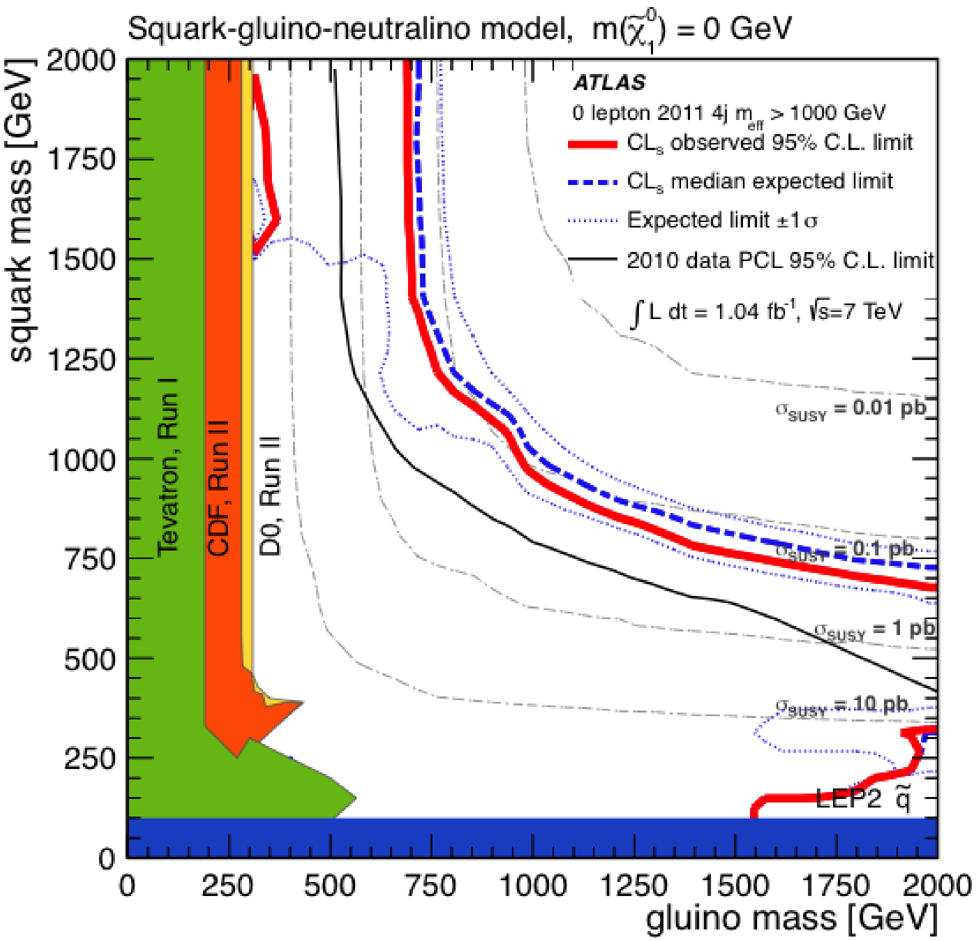
Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0)$ = 0 GeV
ATLAS
0 lepton 2011 2j m_{eff} > 1000 GeV
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
2010 data PCL 95% C.L. limit
$\int L\,dt$ = 1.04 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
LEP2 $\tilde{q}$
Tevatron, Run I
CDF, Run II
D0, Run II
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000

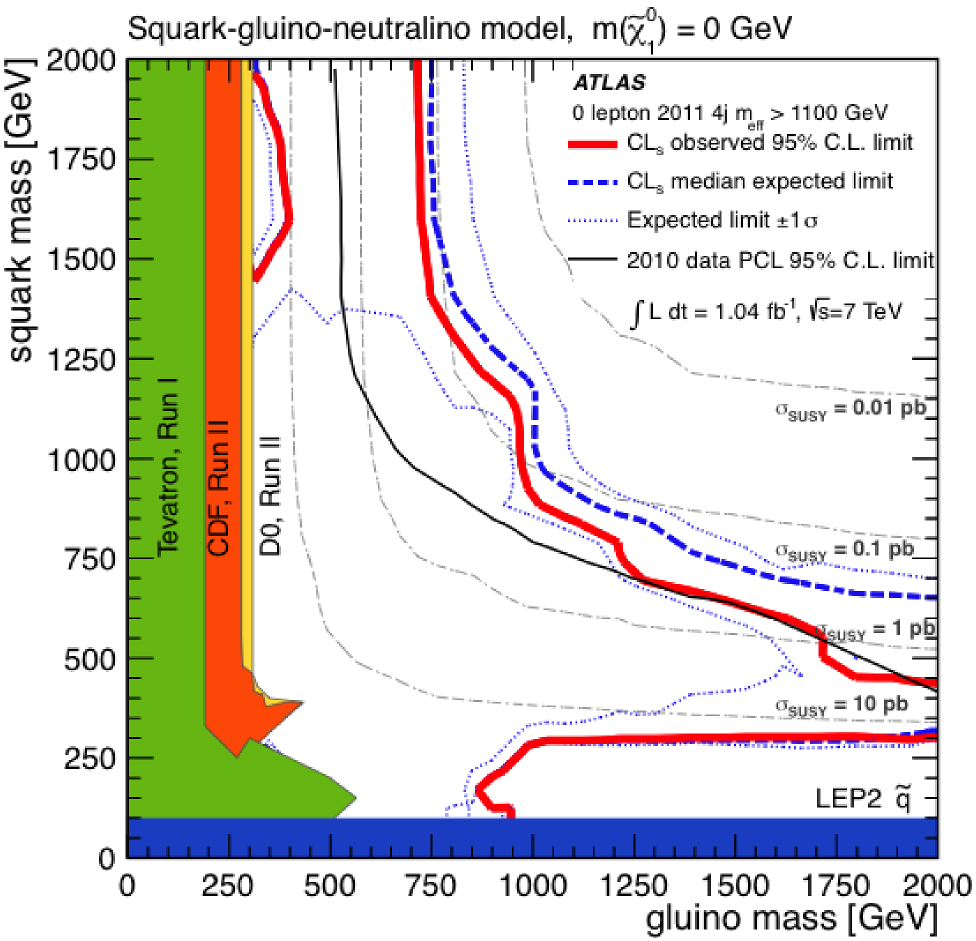


Squark-gluino-neutralino model, m($\tilde{\chi}_1^0$) = 0 GeV
ATLAS
0 lepton 2011 3j m_{eff} > 1000 GeV
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
2010 data PCL 95% C.L. limit
$\int L\,dt$ = 1.04 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
LEP2 $\tilde{q}$
Tevatron, Run I
CDF, Run II
D0, Run II
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000



Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0) = 0$ GeV
ATLAS
0 lepton 2011 4j m_{eff} > 500 GeV
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit $\pm 1\sigma$
2010 data PCL 95% C.L. limit
$\int L\,dt = 1.04\ fb^{-1}$, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
Tevatron, Run I
CDF, Run II
D0, Run II
LEP2 $\tilde{q}$
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000


Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0) = 0$ GeV
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000
ATLAS
0 lepton 2011 4j $m_{eff} > 1000$ GeV
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit $\pm 1\sigma$
2010 data PCL 95% C.L. limit
$\int L\,dt = 1.04\ fb^{-1}$, $\sqrt{s}=7$ TeV
$\sigma_{SUSY} = 0.01$ pb
$\sigma_{SUSY} = 0.1$ pb
$\sigma_{SUSY} = 1$ pb
$\sigma_{SUSY} = 10$ pb
Tevatron, Run I
CDF, Run II
D0, Run II
LEP2 $\tilde{q}$



Squark-gluino-neutralino model, m($\tilde{\chi}_1^0$) = 0 GeV
ATLAS
0 lepton 2011 4j m_{eff} > 1100 GeV
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
2010 data PCL 95% C.L. limit
$\int L\,dt$ = 1.04 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
LEP2 $\tilde{q}$
Tevatron, Run I
CDF, Run II
D0, Run II
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000