Recent Results from BSM Searches at ATLAS (including SUSY)

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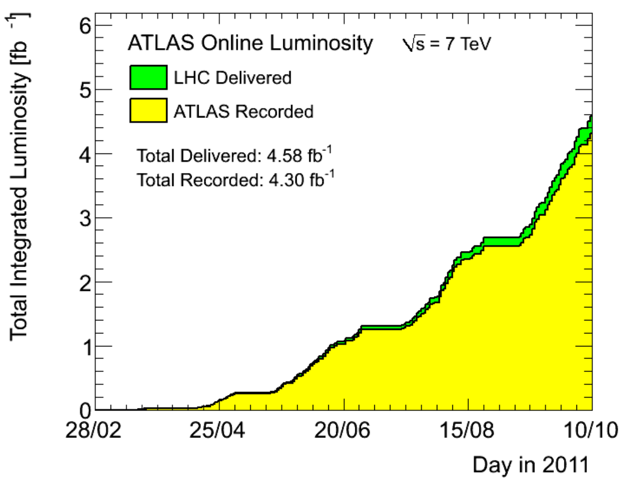
Introduction

- The Standard Model does not correctly describe nature at high energy scales
- Many searches ongoing within ATLAS to test for deviations from the SM
  - Integrated Luminosity rapidly increasing
  - Sensitive to many new physics models/signatures
- Relatively "model independent" searches, in specific final states, simultaneously probe multiple proposed models



Introduction

Signature	Models Probed / Particles Searched
Dijets	excited quark axigluon color octet scalar
4 Leptons	doubly charged Higgs massive graviton
Jets + MET + 1 Lepton (Backup)	pair-produced quark-like objects
Dileptons (Backup)	low scale technicolor

Exotics

SUSY

Signature	Models Probed / Particles Searched
Jets + MET	MSUGRA/CMSSM light squark, gluino, neutralino
eμ resonance	RPV SUSY LFV Z'
Jets + MET + 1 Lepton (Backup)	MSUGRA/CSSM bilinear RPV SUSY light squark/gluino, chargino, neutralino

*Lepton is used here and throughout to refer to electrons and muons only

Exotics

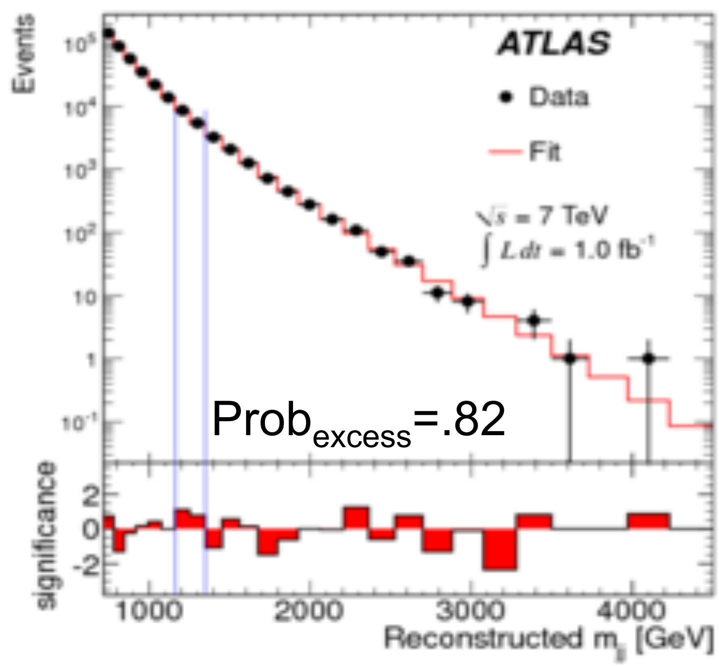
Dijets

- pp➔jj has a very large cross section
  - Can probe very high dijet masses already (~4 TeV)
- Sensitive to variety of colored BSM particles
  - Excited quark, axigluon, color octet scalar

$$L_{gg8} = g_{QCD} d^{ABC} \frac{1}{\Lambda_s} S_8^A F_{\mu\nu}^B F^{C,\mu\nu}$$

$$qg \Rightarrow q^* \Rightarrow qV \qquad L_{Aq\bar{q}} = g_{QCD} \bar{q} A_\mu^a \frac{\lambda^a}{2} \gamma^\mu \gamma_5 q$$

- $|\eta_j|<2.8$, $|y^*|<.6$, $m_{jj}>717$GeV
- Search for bump in m_{jj} distribution
  - Data fit to $f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x}$
    where $x \equiv m_{jj}/\sqrt{s}$ (p-value$_{fit}$=.96)
  - BumpHunter Algorithm

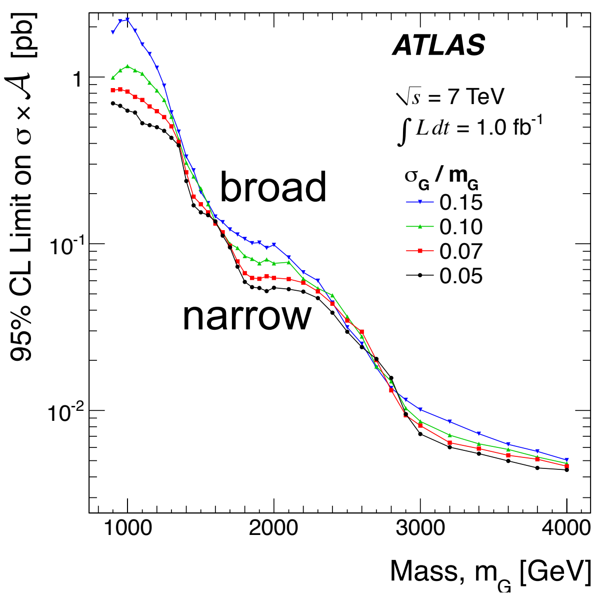


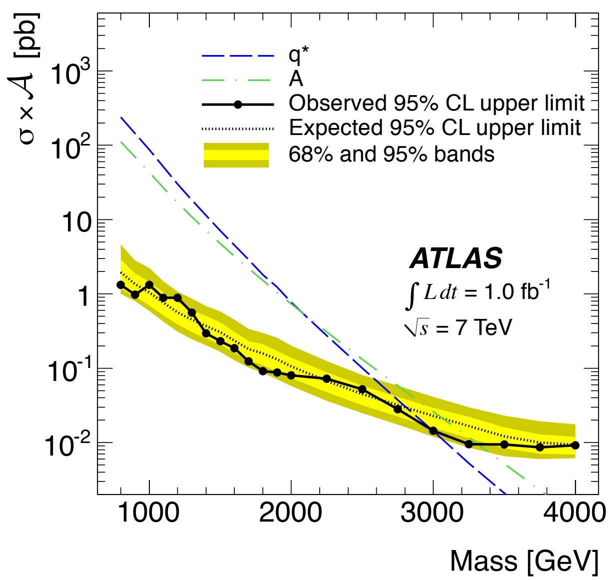
arxiv:1108.6311

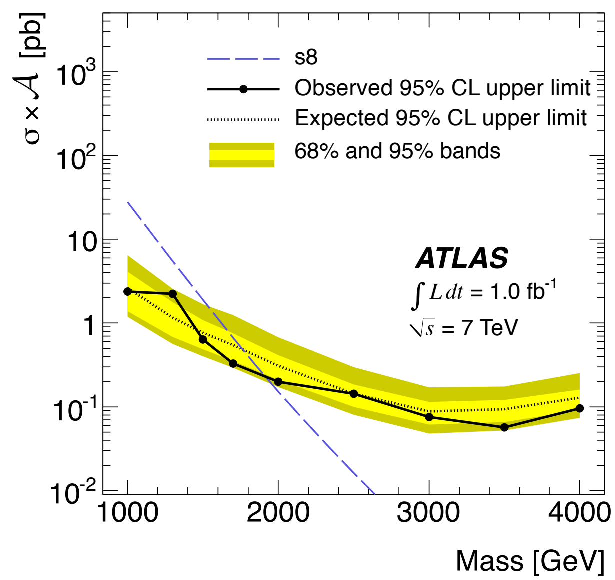
Dijets

Systematic uncertainties dominated by JES, reduce m_{limit} by ~60GeV

Model independent exclusion







m_{q^*} > 2.99TeV

$m_{axigluon}$ > 3.32 TeV

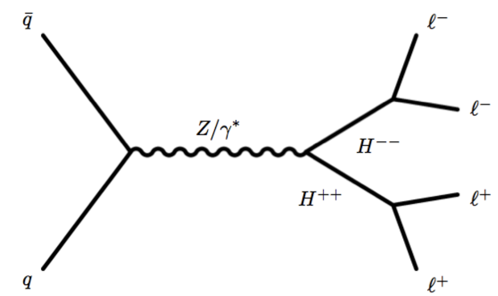
$m_{color\ octet}$ > 1.92 TeV

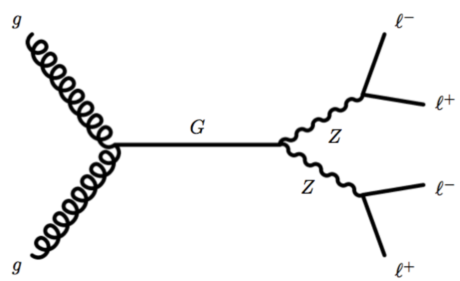
Most stringent limits to date

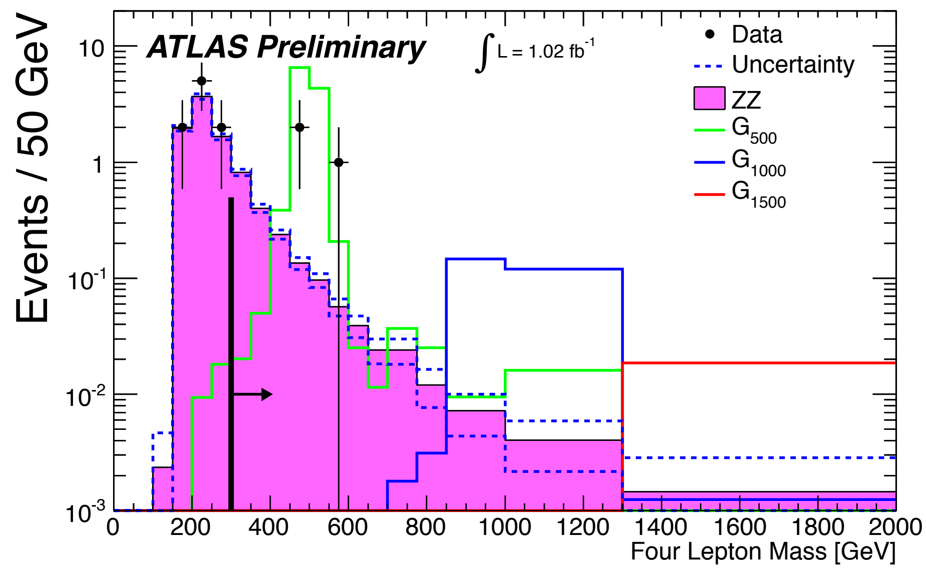
4 Leptons

- Many BSM models lead to multi-lepton production
- 2 channel search
  - 0 OS SF lepton pairs within Z window [66,116] GeV
    - Doubly charged Higgs, seesaw type II and II models
    - $0.7^{+1.3}_{-0.6}(stat)^{+0.9}_{-0.5}(syst)$ events expected, 0 observed
  - 2 OS SF lepton pairs within Z window, $m_{ZZ} > 300$GeV
    - RS graviton, warped ED, GUTs
    - $1.87^{+1.04}_{-0.11}(stat)^{+0.75}_{-0.09}(syst)$ events expected, 3 observed (median)
    - Does not confirm "CDF bump"

arxiv:1104.0699





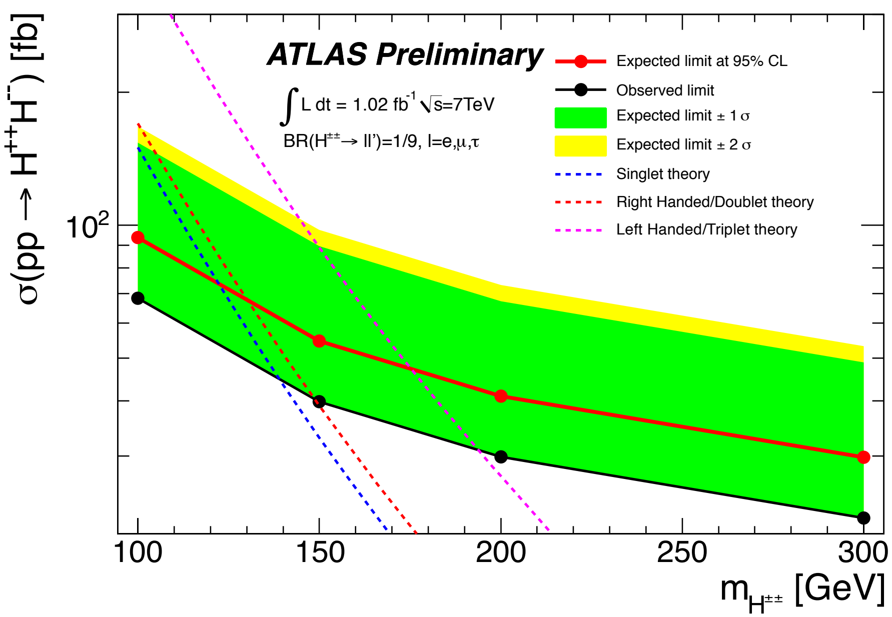


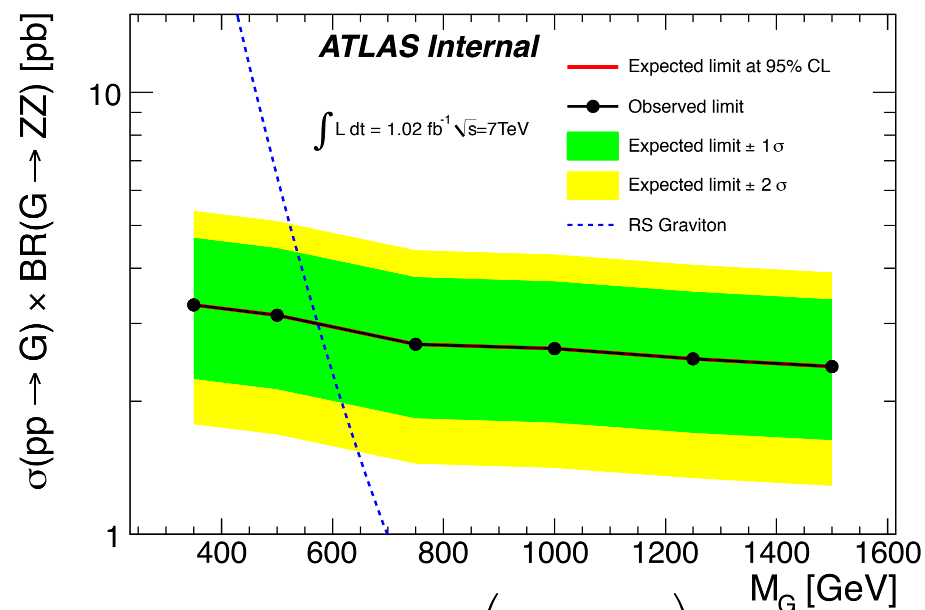
ATLAS-CONF-2011-144

4 Leptons

Systematic uncertainties dominated by lepton reconstruction efficiency (<6.6%)

$$\sigma_{4\ell}^{fid} < 4.7\,fb \qquad \sigma_{ZZ}^{fid} < .92\,fb$$

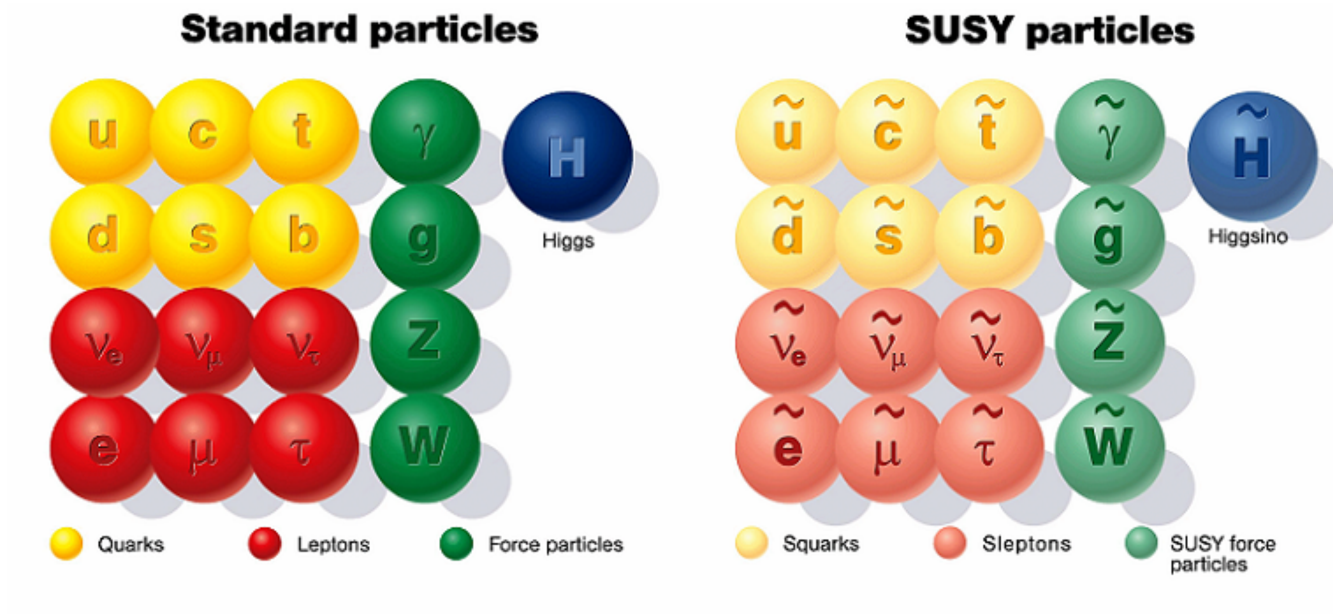




$$m_G > 575GeV \quad \left(\frac{k}{M_{pl}} = .1\right)$$

$$\sigma(pp \Rightarrow G_{RS}) \times BR(G_{RS} \Rightarrow ZZ) < 2.6 - 3.3\,fb$$

SUSY



$$m_{eff} = MET + \sum_{jets} p_T + \sum_{leptons} p_T$$

$$m_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{miss} \cdot \left(1 - \cos\left(\Delta\phi\left(\vec{\ell}, \vec{E}_T^{miss}\right)\right)\right)}$$

Jets + MET

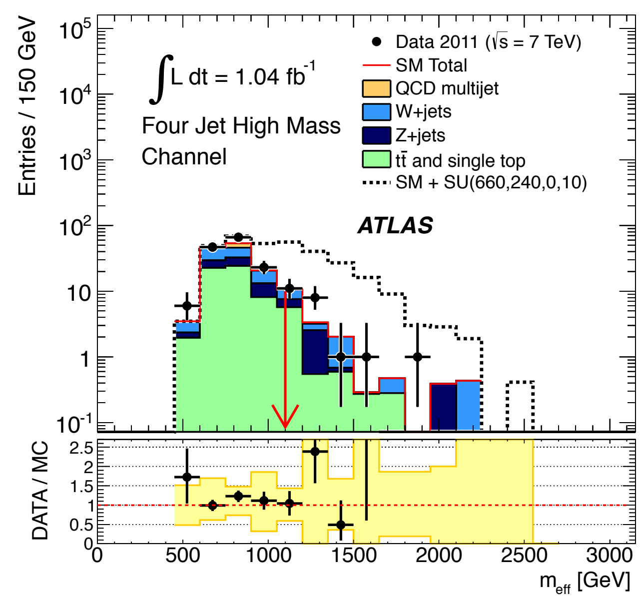
- If squarks or gluons are light, they could be produced copiously at the LHC

$$\begin{cases} gg \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q} \\ gq \to \tilde{g}\tilde{q} \\ qq \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q} \end{cases}$$

- Decay via $\tilde{q} \to q\tilde{\chi}_1^0$ and $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$
  - Final states consisting of 2,3, or 4 jets and MET
- 5 separate signal regions defined
  - 5 control regions for each SR
  - Combined likelihood fit to data in CRs determines background normalizations
  - Transfer factors determine yields in SR

$$TF^{CR_B}_{background_A} \equiv \frac{N^{SR}_{background_A}}{N^{CR_B}_{background_A}}$$

SR	1	2	3	4	High Mass
$N_{jets} \geq$	2	3	4		4
MET >	130				
leading jet p_T >	130				
sub-leading jet p_T >	40	40	40		80
$\Delta\phi(\text{jet,MET})_{min}$ >	.4				
MET/m_{eff} >	.3	.25	.25	.25	.2
m_{eff} >	1000	1000	500	1000	1100

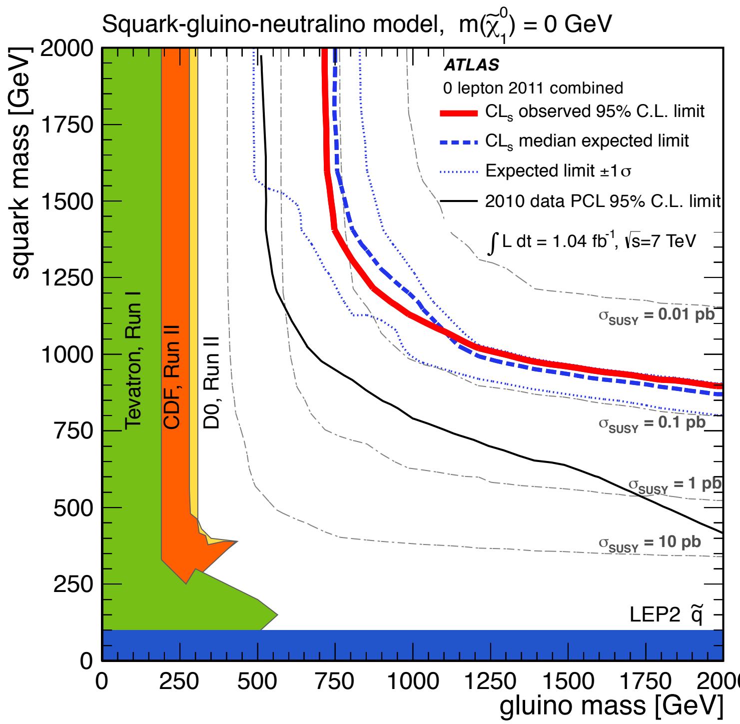


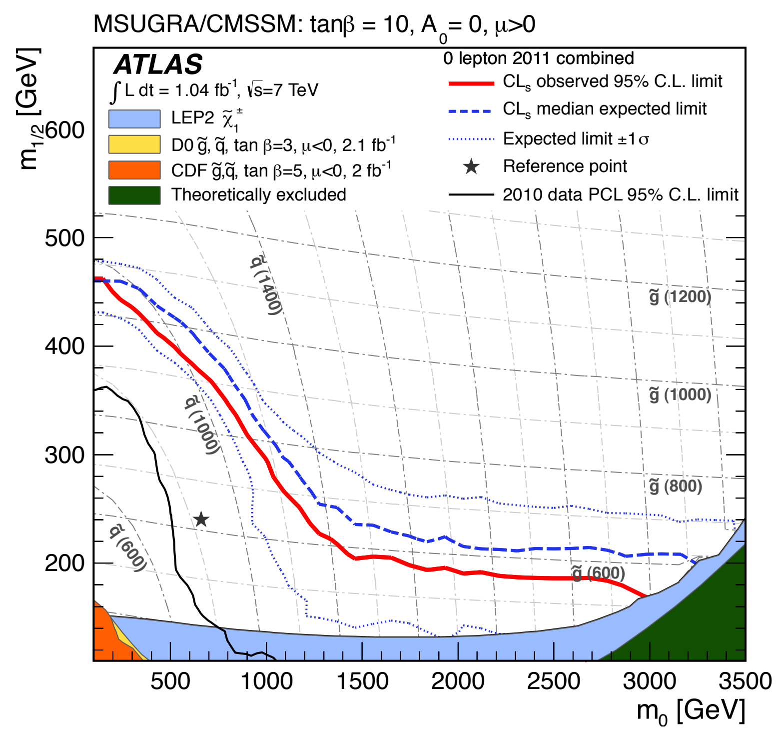
arxiv:1109.6572

Jets + MET

Systematics dominated by jet energy scale/resolution and signal modeling (~30-40%)

σ_{new} < 22 fb, 25 fb, 429 fb, 27 fb and 17 fb





for heavy squark: m_{gluino} > 700GeV

for heavy gluino: m_{squark} > 875GeV

degenerate case: m > 1075GeV

small m_0: $m_{1/2}$ > 460GeV

$m_{squark} = m_{gluino}$: m > 950GeV

arxiv:1109.3089

e-μ Resonance

- Many BSM theories predict the existence of particles which decay to 2 leptons of different flavors
  - Sneutrino in RPV SUSY $d\bar{d} \rightarrow \tilde{\nu}_\tau \rightarrow e^\pm \mu^\mp$
  - LFV Z′
  - Any narrow particle which decays to eμ

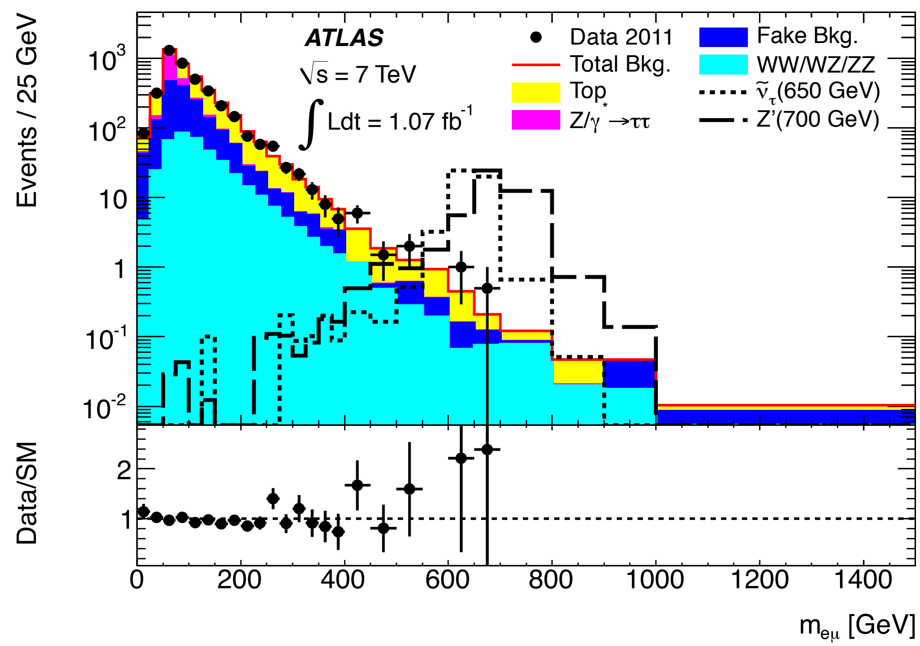
$$L = \frac{1}{2}\lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}_k$$

$\hat{L},\hat{Q}$ = ℓ and q SU(2) doublet superfields

$\hat{E},\hat{D}$ = ℓ± and down-type quark singlet fields

- Require exactly 1 e and 1 OS μ
  - Search for bump in the eμ invariant mass distribution
- 4x4 Matrix Method to estimate fake background

$$\left(N_{pp},N_{pf},N_{fp},N_{ff}\right)^T = \varepsilon\left(N_{e\mu},N_{e\mu^t},N_{e^t\mu},N_{e^t\mu^t}\right)^T$$

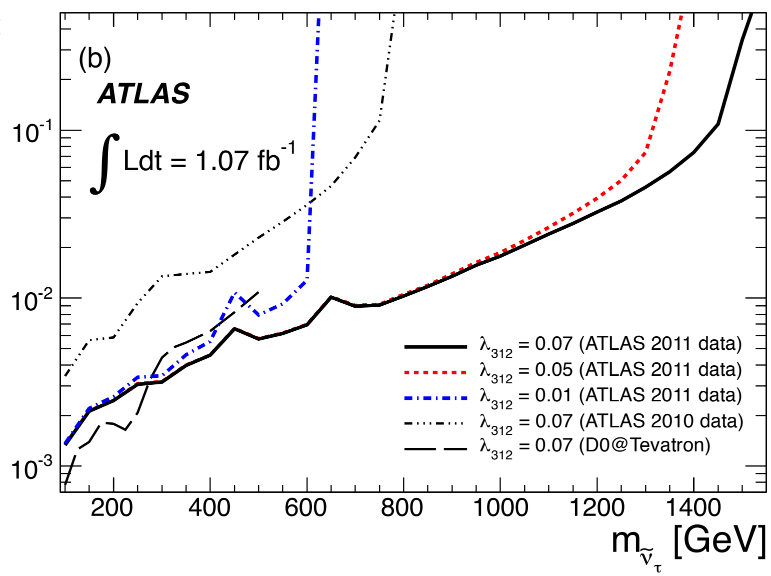


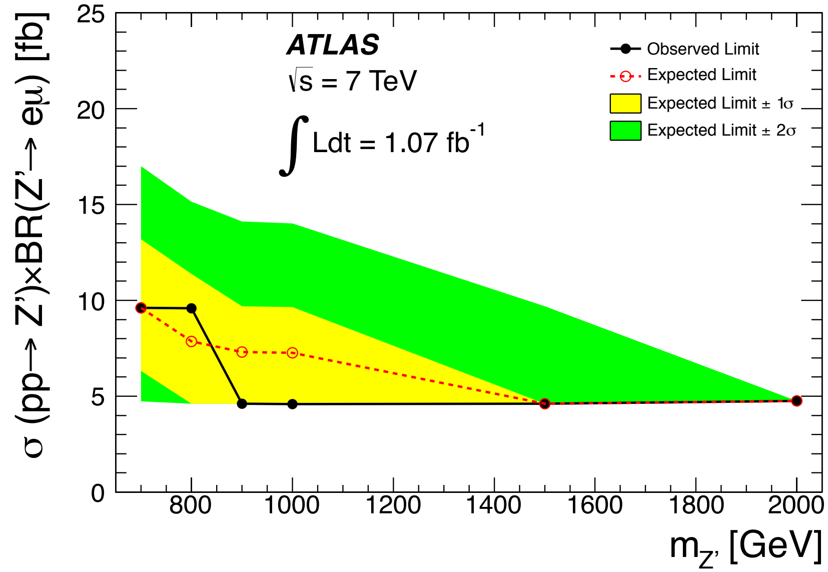
arxiv:1109.3089

e-μ Resonance

$m_{\tilde{\nu}}$ > 1.32 (1.45) TeV excluded, assuming $d\bar{d}\tilde{\nu}_\tau$ coupling = 0.10 (0.11) and $\tilde{\nu}_\tau e^\pm \mu^\mp$ coupling = 0.05 (0.07)

$\tilde{\nu}_\tau e^\pm \mu^\mp$ coupling





$M_{Z'}$ = 0.7 TeV (1.0 TeV): σB < 9.6 fb (4.8 fb)

Conclusion

- BSM search results are being released rapidly
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- No sign of new physics yet
  - Maybe more data is needed, or maybe we just haven't probed the right region of model/parameter space
- Exclusion limits getting stronger and stronger
- Cleaner signatures with smaller cross sections or branching ratios will soon become accessible

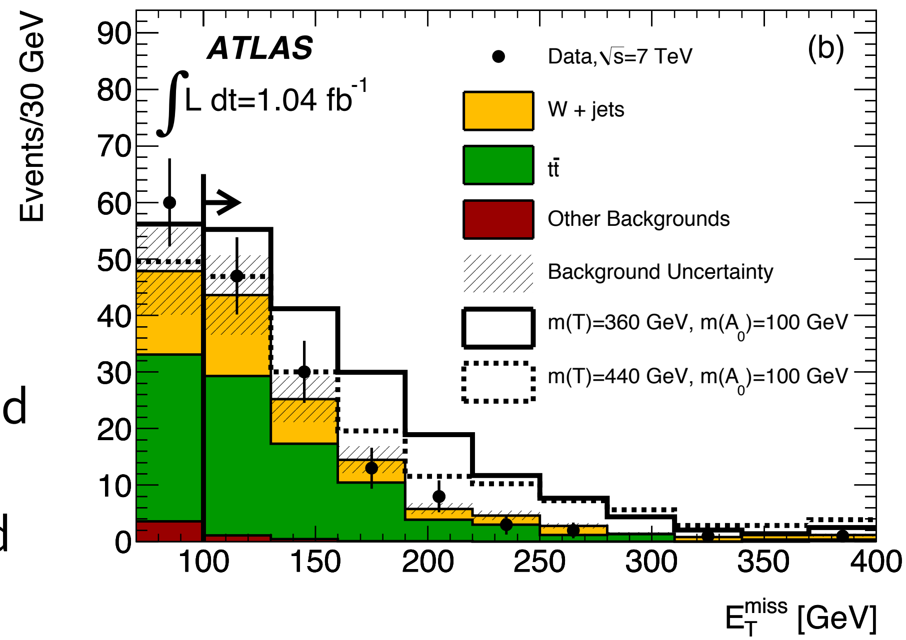
Backup

CERN-PH-EP-2011-149

Jets + MET + 1 Lepton

- Solutions of the hierarchy problem often involve light partners of the top quark
- Search for pair-produced, quark-like, exotic partner of the top, decaying to top and stable, neutral, weakly-interacting particle
  - 4^{th} generation quark, SUSY, little Higgs w/ P_T, UED w/ P_{KK}, 3^{rd} generation LQ, dark matter modelas
  - ttbar+large MET signature
- Signal region
  - $N_\ell=1$, $N_j \geq 4$, MET>100GeV , m_T>150GeV
  - Normalization and shape of m_T derived from data
  - 101±16 events expected, 105 observed

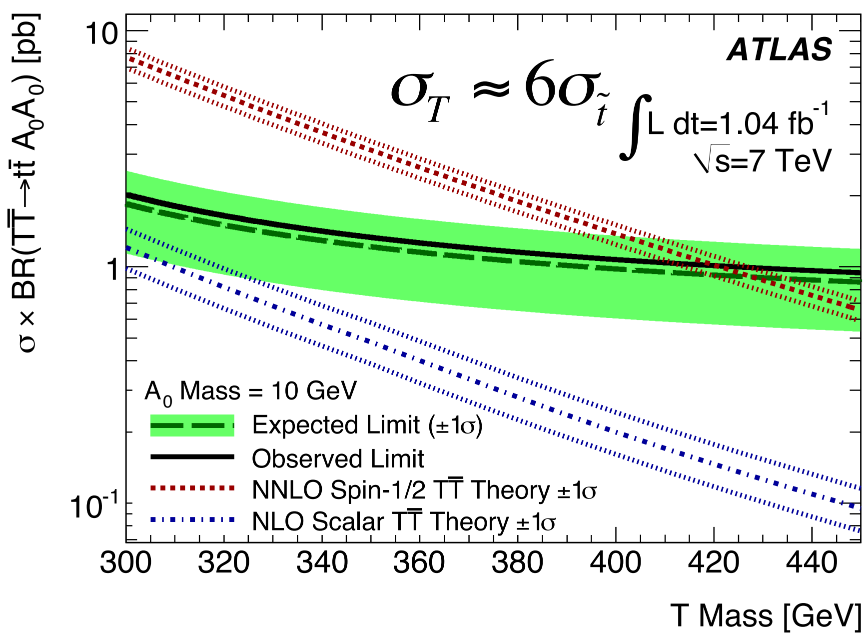
$$BR(T\bar{T} \rightarrow t\bar{t}A_0A_0) = 1$$

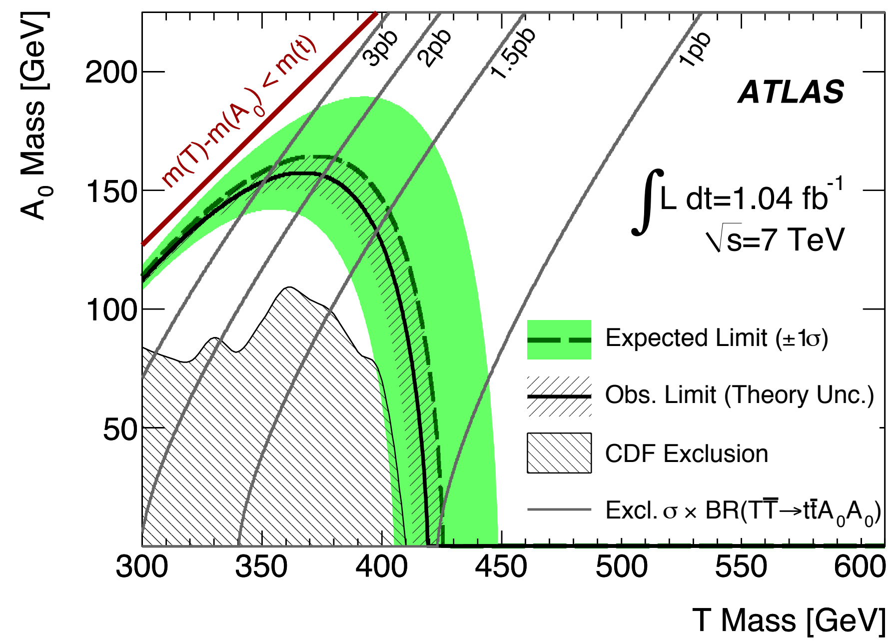


CERN-PH-EP-2011-149

Jets + MET + 1 Lepton

Systematics dominated by JES (11% uncertainty on SR yield)





σ*BR < 1.1(1.9)pb for m_T = 420(370)GeV and m_{A0}=10(140)GeV

m_T>420GeV for $m_{A0}\leq$10GeV

ATLAS-CONF-2011-125

Dileptons

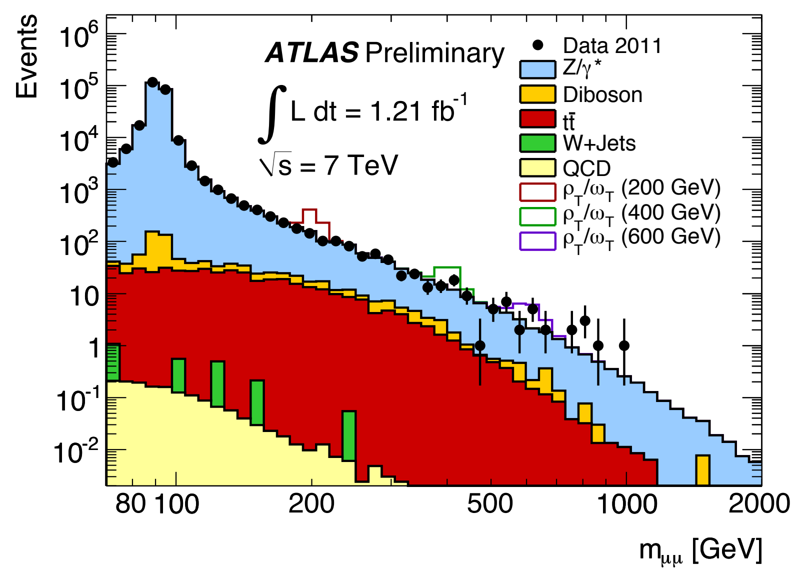
- Technicolor provides an alternative mechanism for electroweak symmetry breaking
- Introduces new low-mass states ($\pi_T^{\pm,0}, \rho_T^{\pm,0}, \omega_T^0$) that could be produced in abundance at the LHC
- "CDF bump" could be explained by:

arxiv:1104.0699

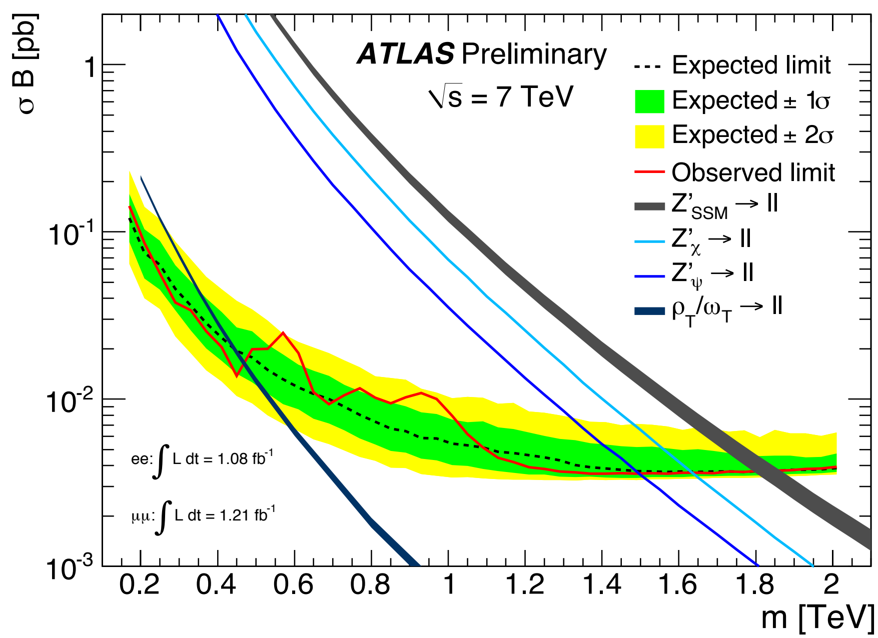
$$\rho_T^{290GeV} \to W\pi_T^{160GeV}$$

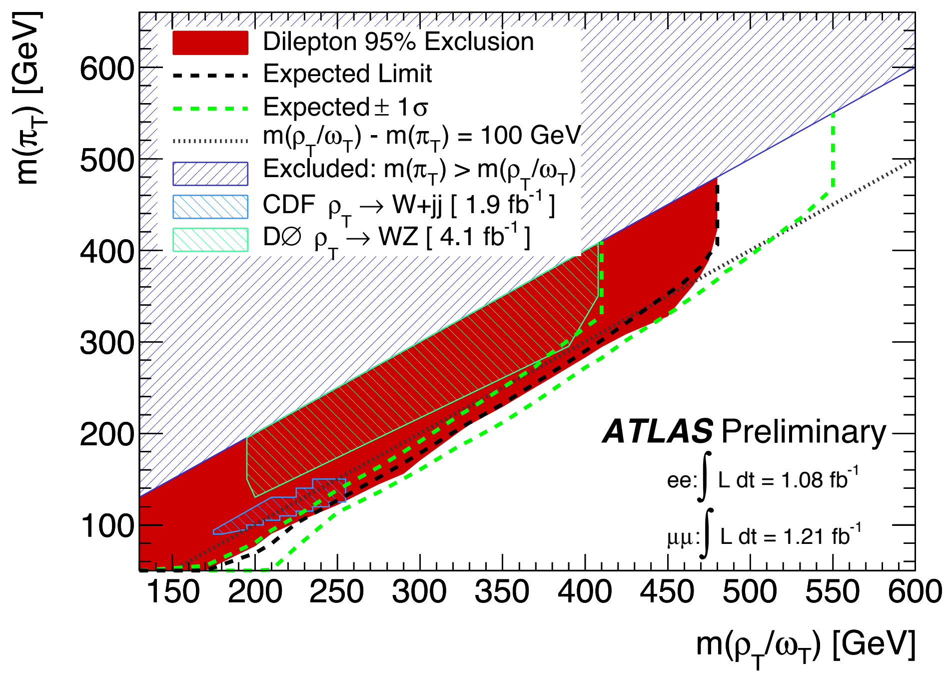
$$\left.\begin{array}{c}\omega_T^0\\ \rho_T^{\pm,0}\end{array}\right\} \to \left\{\begin{array}{c}V\pi_T\\ VV\\ f\bar{f}\end{array}\right.$$

- Search for $\rho_T^0, \omega_T^0 \to \ell^+\ell^-$ in context of low scale techni-color model
  - Assume techni-isospin is a good symmetry ($m_{\rho_T} = m_{\omega_T}$)
  - Narrrow spin-1 resonances ➔ same analysis methodology as Z′ search



Dileptons

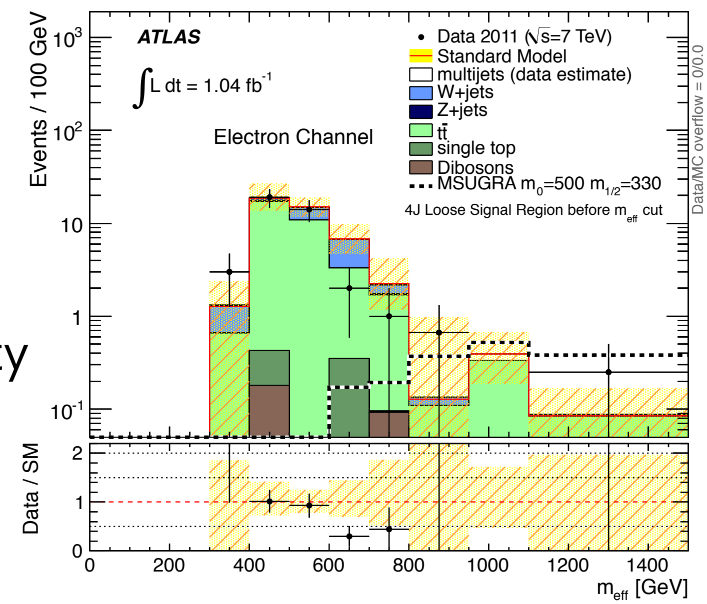




$m_{\rho_T \omega_T}$ from 130-480GeV excluded for m_{π_T} = 50-480GeV

Jets + MET + 1 Lepton

- Consider two simplified models
  - Light squark, chargino, neutralino $\tilde{q} \rightarrow q' \tilde{\chi}_1^{\pm}$
  - Light gluino, chargino, neutralino $\tilde{g} \rightarrow q\bar{q} \tilde{\chi}_1^{\pm}$
  - Assume $B(\chi_1^{\pm} \rightarrow W^{(*)} \chi_1^0) = 1$, and search for events with semi-leptonic W decays
  - Also interpreted in context of MSUGRA/CMMSM, and model with bilinear RPV
- Final state consists of 4 or 6 jets, MET, and 1 lepton
- 4 separate signal regions defined
  - N_{jet}, MET, $p_T(jet_i)$ m_{eff}, MET/m_{eff}, m_T
  - To determine exclusion, SR with best sensitivity is chosen for each point in parameter space
  - Control Regions normalize backgrounds
  - Transfer factors determine yields in SR

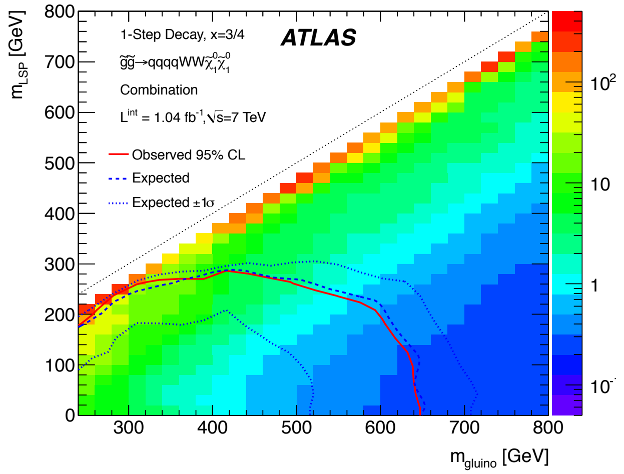


arxiv:1109.6606

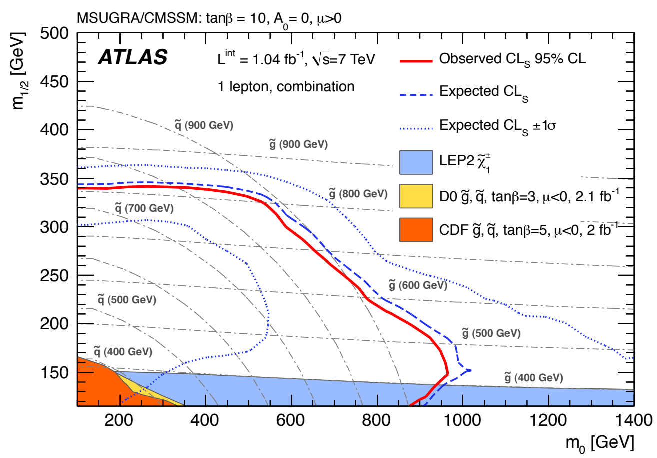
Jets + MET + 1 Lepton

Systematics dominated by jet energy scale and background modeling uncertainties

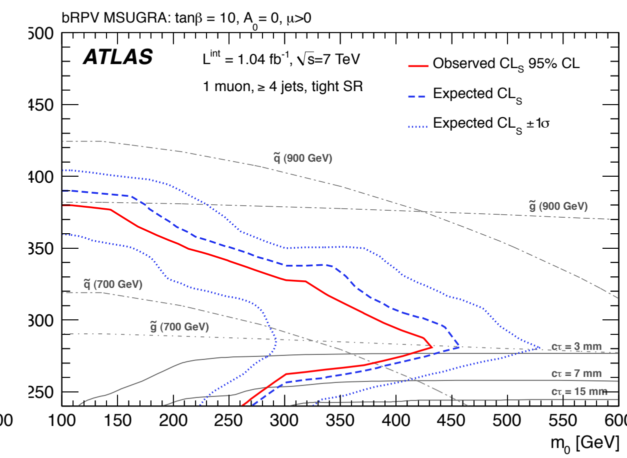
color coding represent model independent σ_{new} limit



MSUGRA/MSSM



bRPV



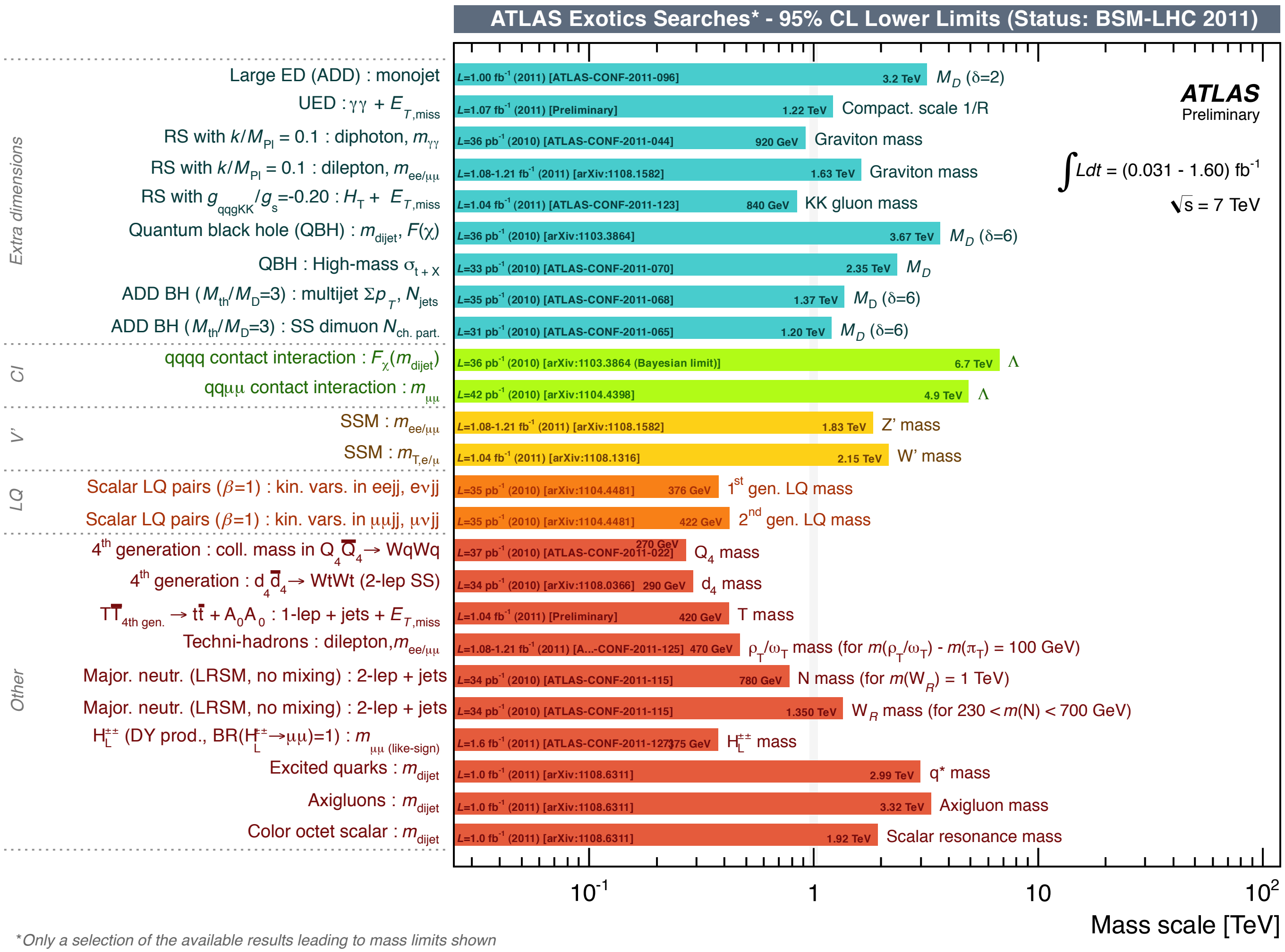
red line represents simplified light gluino model exclusion

$m_{squark} = m_{gluino}$: m > 760GeV

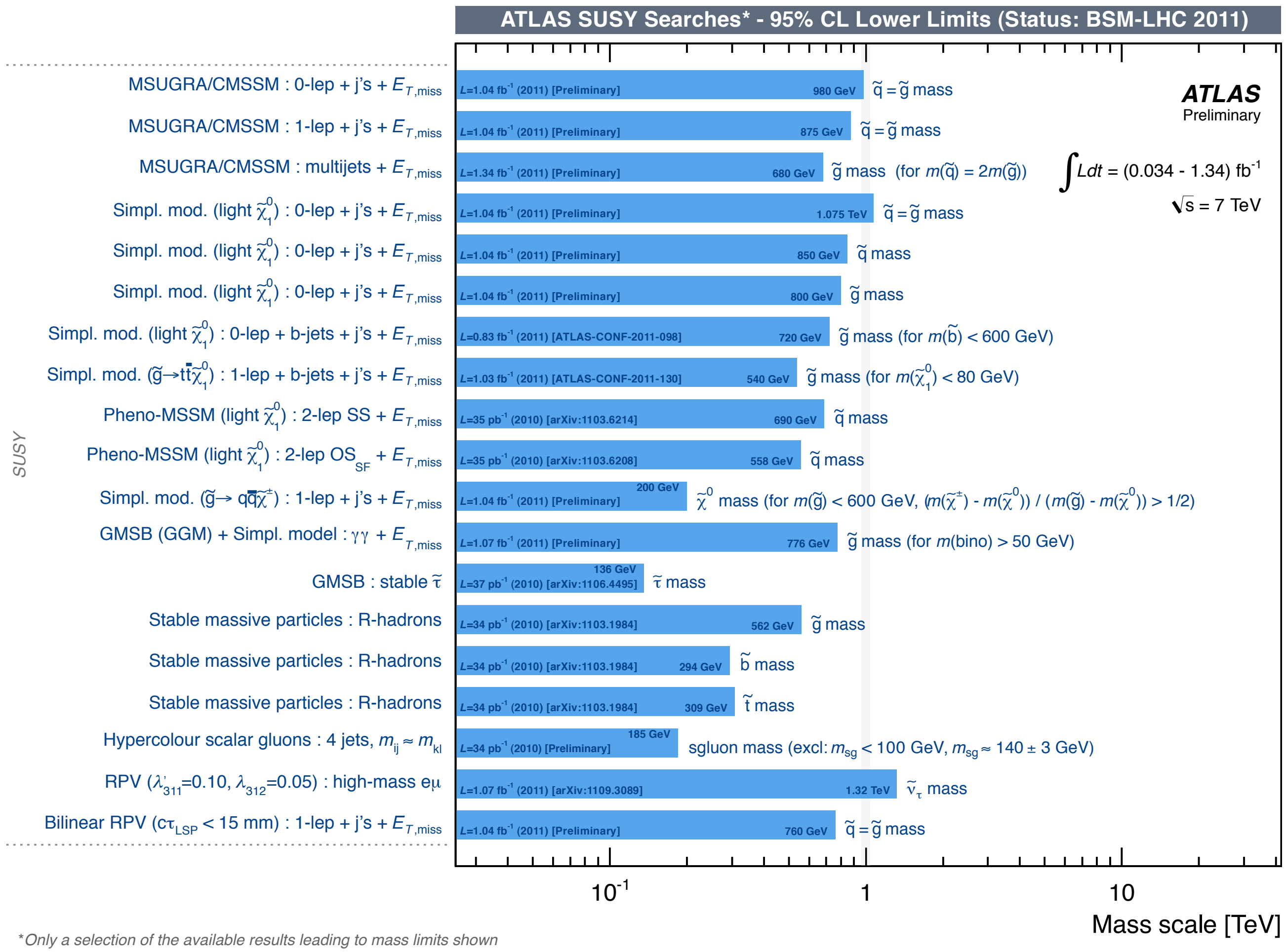
$m_{squark} = m_{gluino}$: m > 820GeV

Additional Info

Exotics Summary



SUSY Summary



4 Leptons

0 Z candidate channel

Process	Total	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\mu^+\mu^-e^+e^-$
ZZ	$0.10 \pm 0.01 \pm 0.01$	$0.02 \pm 0.00 \pm 0.00$	$0.03 \pm 0.01 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.01$
Fakes	$0.61^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$	$0.01 \pm 0.01 \pm 0.01$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+0.01}_{-0.00}{}^{+0.01}_{-0.00}$
Total Bkg.	$0.71^{+1.25}_{-0.61}{}^{+0.91}_{-0.51}$	$0.02 \pm 0.01 \pm 0.01$	$0.03^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.01 \pm 0.01 \pm 0.01$
$H^{\pm\pm}_{200}$	$1.27 \pm 0.04 \pm 0.03$	$0.05 \pm 0.01 \pm 0.01$	$0.09 \pm 0.01 \pm 0.01$	$0.13 \pm 0.01 \pm 0.01$	$0.16 \pm 0.01 \pm 0.01$
Data	0	0	0	0	0

Process	$e^+e^-\ell\ell$	$\mu^+\mu^-\ell\ell$	$e^\pm\mu^\mp\ell\ell$	4 same-sign
ZZ	$0.01 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00$	$0.00 \pm 0.00 \pm 0.00$	$0.01 \pm 0.01 \pm 0.00$
Fakes	$0.61^{+0.69}_{-0.61} \pm 0.51$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$
Total Bkg.	$0.61^{+0.69}_{-0.61} \pm 0.51$	$0.02^{+1.03}_{-0.02}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.01^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$
$H^{\pm\pm}_{200}$	$0.30 \pm 0.02 \pm 0.02$	$0.37 \pm 0.02 \pm 0.02$	$0.18 \pm 0.01 \pm 0.01$	$0.00 \pm 0.00 \pm 0.00$
Data	0	0	0	0

2 Z candidate channel

Process	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\mu^+\mu^-e^+e^-$
ZZ	$0.32 \pm 0.03 \pm 0.01$	$0.63 \pm 0.04 \pm 0.03$	$0.53 \pm 0.04 \pm 0.03$	$0.37 \pm 0.03 \pm 0.02$
Fakes	$0.00^{+0.04}_{-0.00}{}^{+0.03}_{-0.00}$	$0.00^{+1.03}_{-0.00}{}^{+0.75}_{-0.00}$	$0.00^{+1.03}_{-0.01}{}^{+0.75}_{-0.00}$	$0.02 \pm 0.02 \pm 0.02$
Total Bkg.	$0.32^{+0.05}_{-0.03}{}^{+0.03}_{-0.01}$	$0.63^{+1.03}_{-0.04}{}^{+0.75}_{-0.03}$	$0.54^{+1.03}_{-0.04}{}^{+0.75}_{-0.03}$	$0.39 \pm 0.04 \pm 0.03$
Data	0	2	1	0
G(350 GeV)	$12 \pm 1 \pm 1$	$23 \pm 2 \pm 1$	$20 \pm 2 \pm 1$	$16 \pm 1 \pm 1$
G(500 GeV)	$2.1 \pm 0.2 \pm 0.1$	$4.0 \pm 0.3 \pm 0.2$	$3.2 \pm 0.2 \pm 0.2$	$2.3 \pm 0.2 \pm 0.1$
G(750 GeV)	$0.30 \pm 0.02 \pm 0.01$	$0.46 \pm 0.03 \pm 0.01$	$0.43 \pm 0.03 \pm 0.01$	$0.26 \pm 0.02 \pm 0.01$
G(1000 GeV)	$(6.0 \pm 0.5 \pm 0.5) \times 10^{-1}$	$(8.5 \pm 0.6 \pm 0.5) \times 10^{-1}$	$(8.6 \pm 0.6 \pm 0.6) \times 10^{-1}$	$(4.3 \pm 0.4 \pm 0.5) \times 10^{-1}$
G(1250 GeV)	$(1.3 \pm 0.1 \pm 0.1) \times 10^{-2}$	$(2.0 \pm 0.1 \pm 0.1) \times 10^{-2}$	$(2.4 \pm 0.2 \pm 0.1) \times 10^{-2}$	$(0.9 \pm 0.1 \pm 0.1) \times 10^{-2}$
G(1500 GeV)	$(4.1 \pm 0.3 \pm 0.2) \times 10^{-3}$	$(5.6 \pm 0.4 \pm 0.2) \times 10^{-3}$	$(7.0 \pm 0.5 \pm 0.3) \times 10^{-2}$	$(2.6 \pm 0.2 \pm 0.2) \times 10^{-3}$

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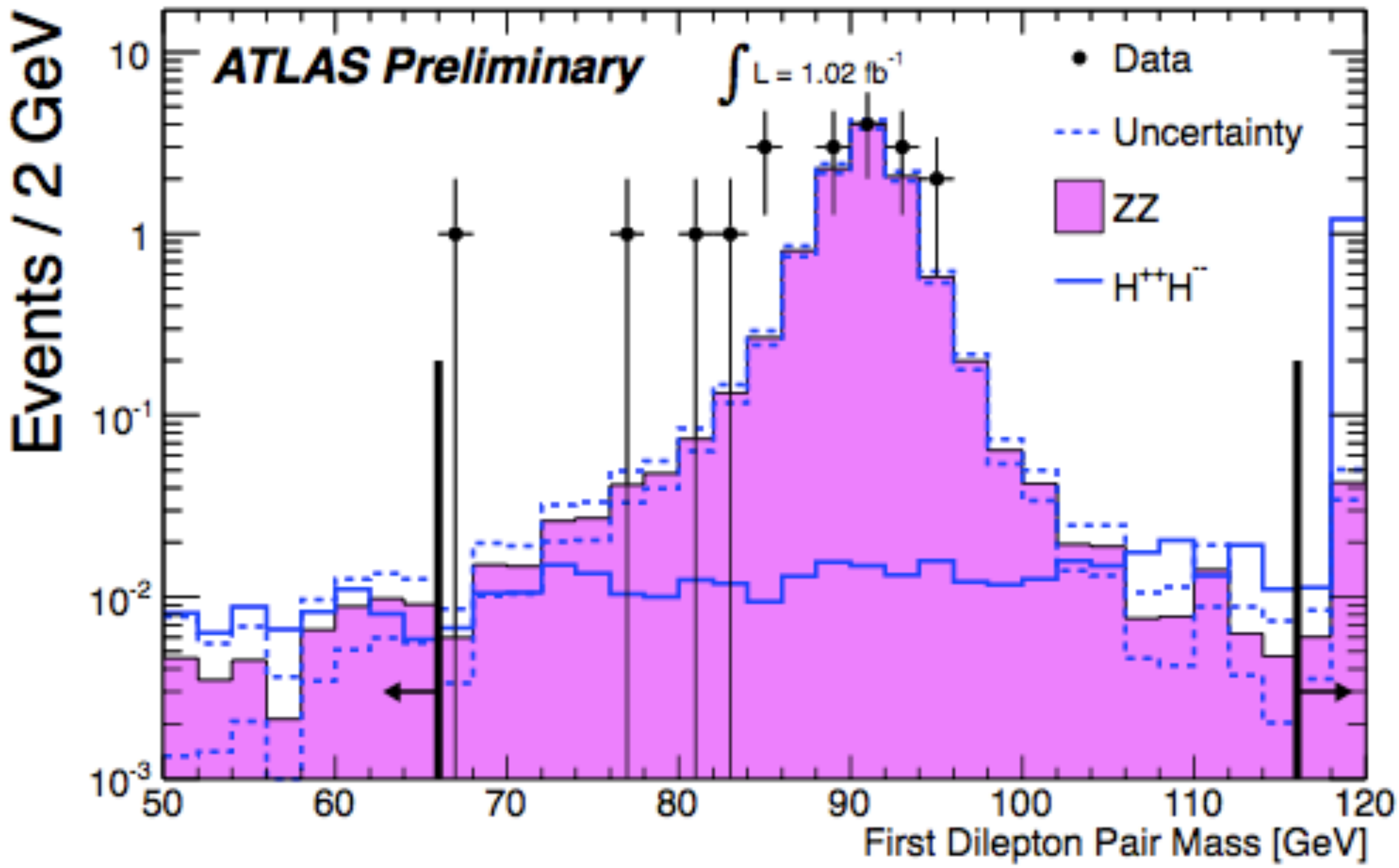
4 Leptons

2 Z candidates



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Jets + MET

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
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

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with control regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (second) quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the total background estimates do not equal the quadrature sums of the uncertainties on the components.

	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

Table 3: Numerical inputs (i.e. the observed numbers of events in data) to and outputs from the likelihood fit to the control regions for the high mass channel. The transfer factor listed in the fourth row applies to the main targeted background for that CR, as listed in the third row. An entry '–' in rows 5–7 indicates that the process in that row is assumed not to contribute to the control region (based on Monte Carlo studies) and hence is excluded from the fit. All numerical entries give event counts, with the exception of the transfer factors in the fourth row.

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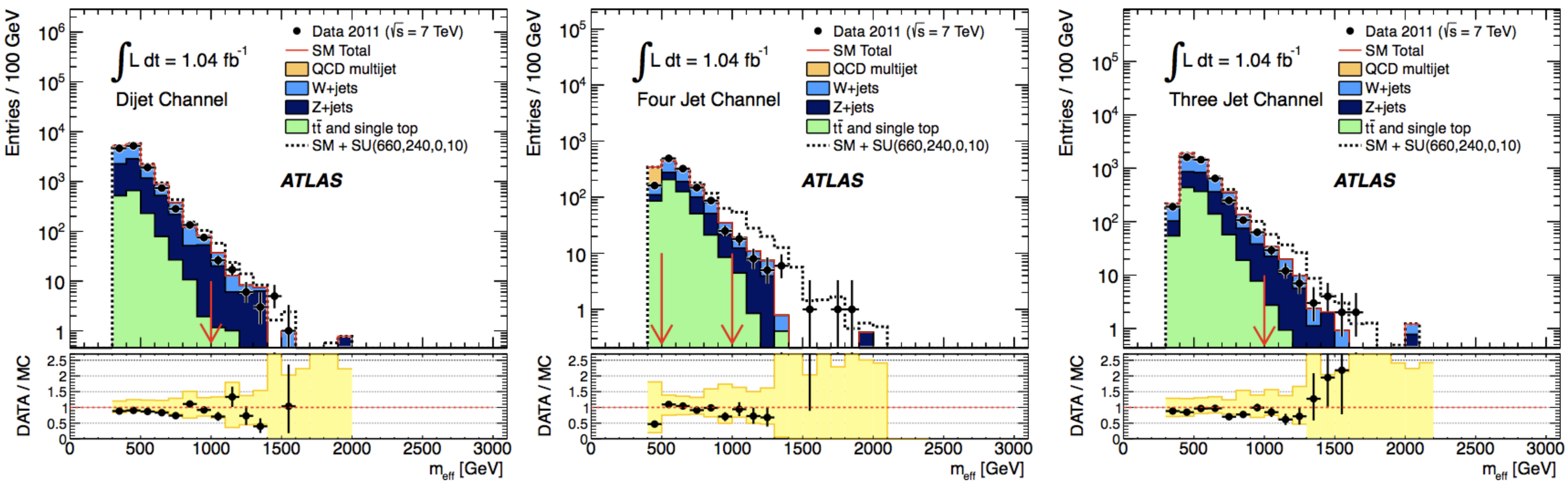
Jets + MET



e-μ Resonance