



Exotics/SUSY Searches for New Physics in ATLAS



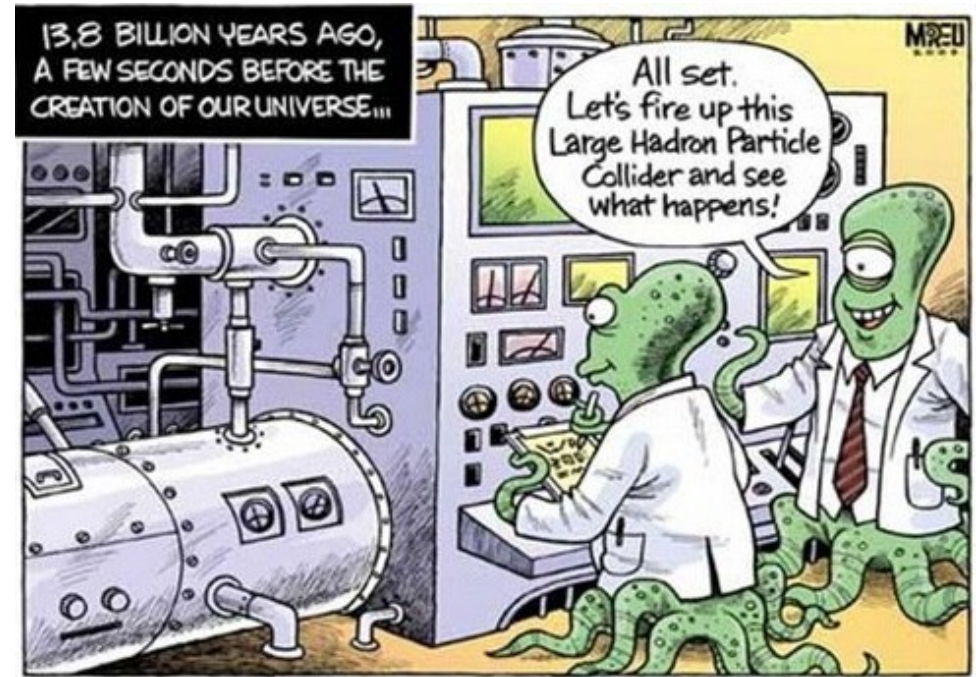
Jalal Abdallah
IFAE – Barcelona

III CPAN Days - Nov 2, 2011



Outline

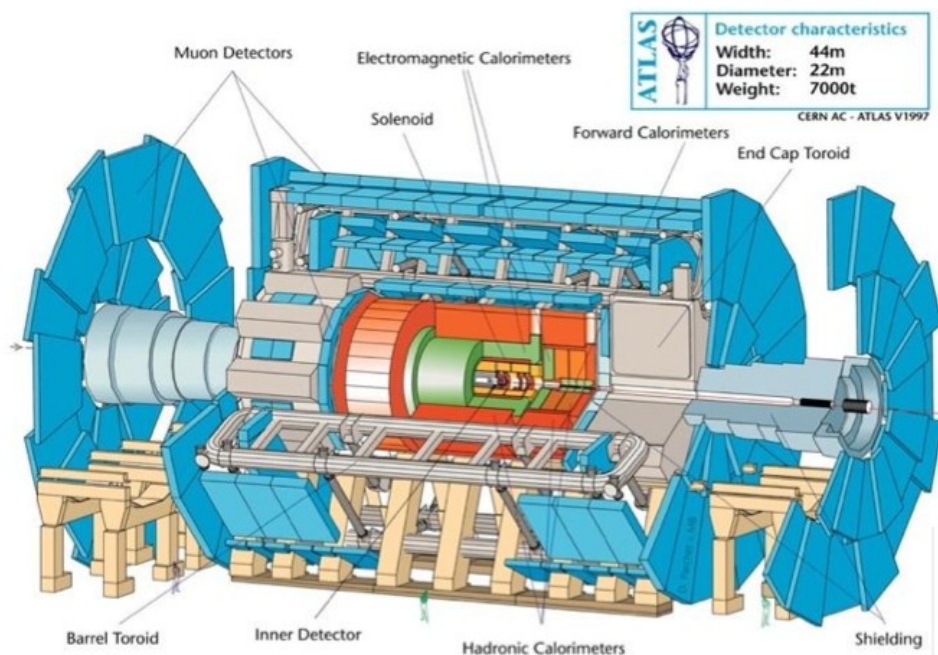
- ATLAS and LHC operations in 2011
- It is very difficult to cover all the SUSY/Exotics searches in ATLAS in 20 min (over 20 CONF notes and 8 papers for early 2011 data). I will focus on:
 - Squarks/gluinos
 - Scenarios with RPV
 - Monojet + MET
 - Dilepton final states
 - Lepton and missing Et
 - Semileptonic $t\bar{t}$
 - Fourth generation quarks
- [ATLAS SUSY public results](#)
- [ATLAS Exotics public results](#)



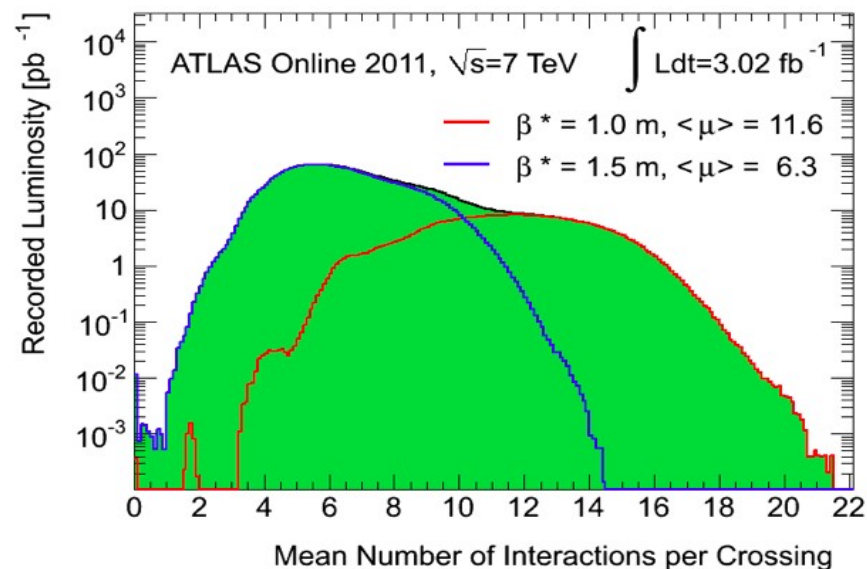
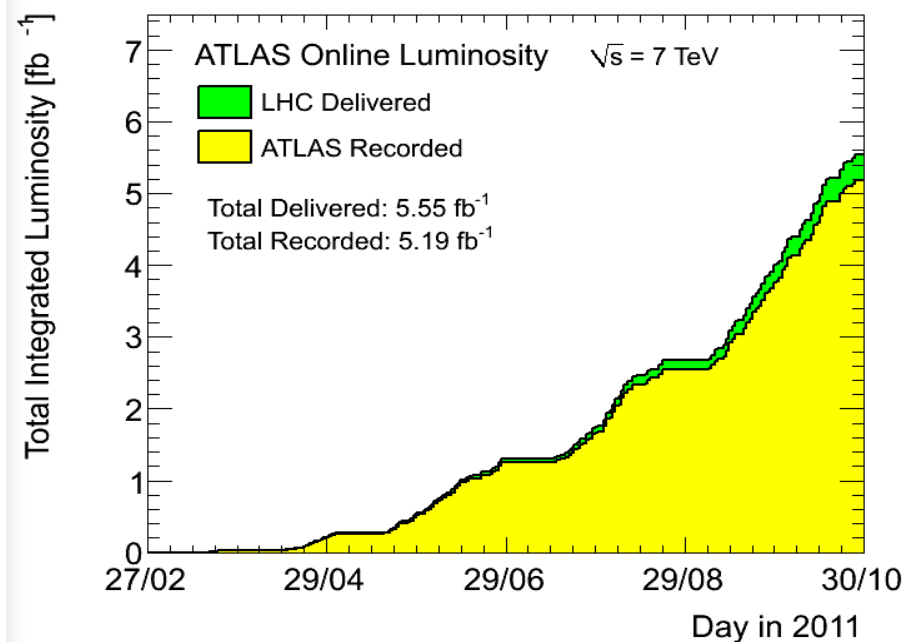
(I will not talk about SUSY Higgs)



ATLAS and LHC Operations

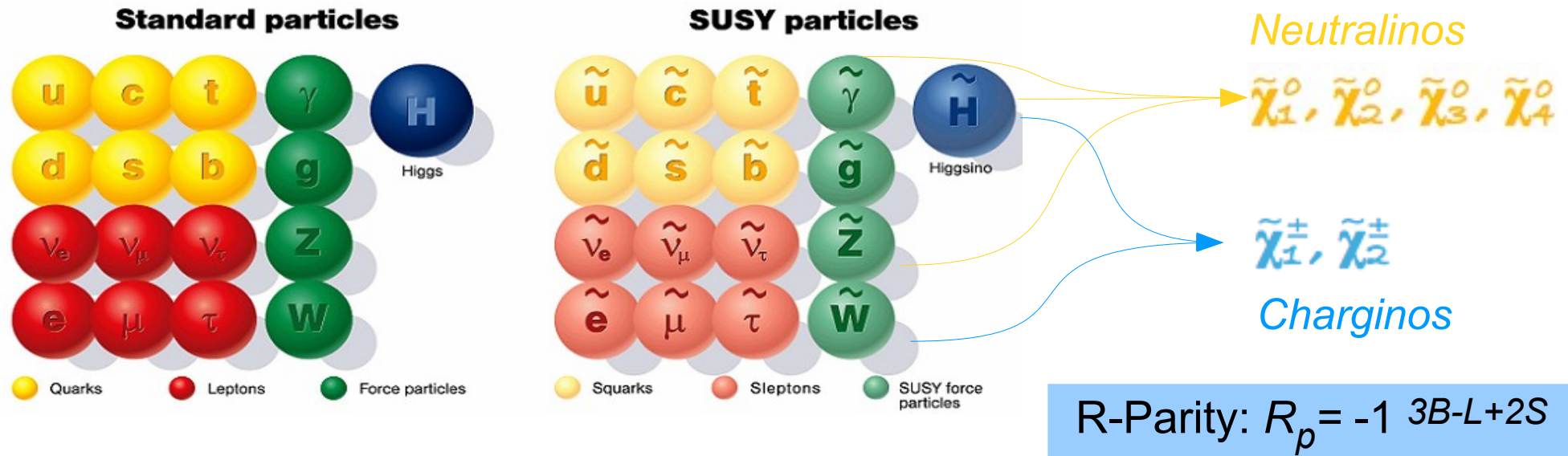


- Very good LHC performance, more than 5.5 fb^{-1} delivered
- ATLAS operations have been very successful with a data taking efficiency of 93.5%.





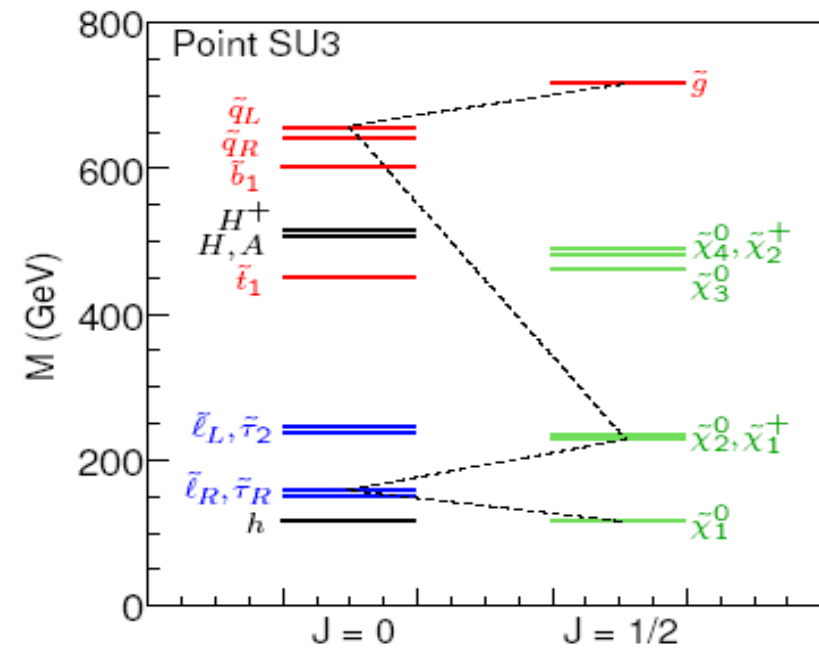
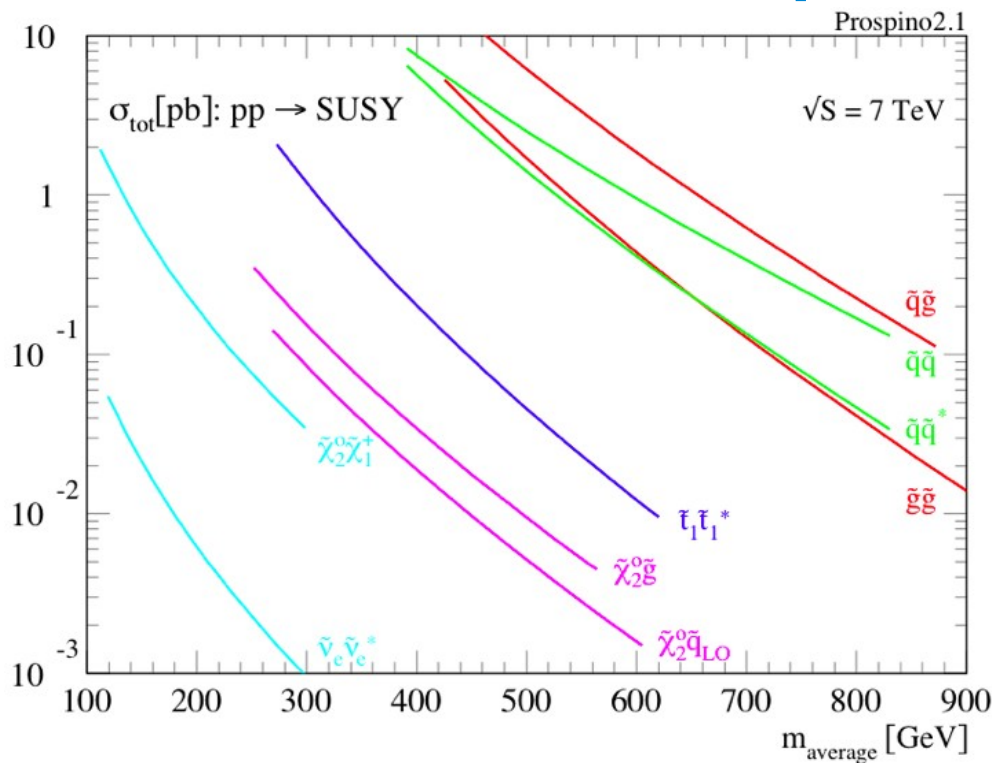
SUPERSYMMETRY



- Symmetry fermion $\Leftrightarrow$ boson: SM particles have SUSY partners with a spin difference $\pm 1/2$.
- SUSY gives a solution to hierarchy problem (Higgs radiative correction loops cancel out) and a DM candidate (if R_p conservation)
- Different scenarios with different topologies for SUSY breaking: mSUGRA, GMSB, AMSB, split SUSY
- Squarks/gluinos can be produced strongly at the LHC

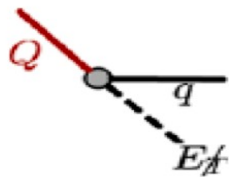


Typical mSUGRA cross sections and Mass spectrum

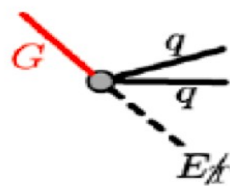


1 or more leptons + jets + E_T^{miss}

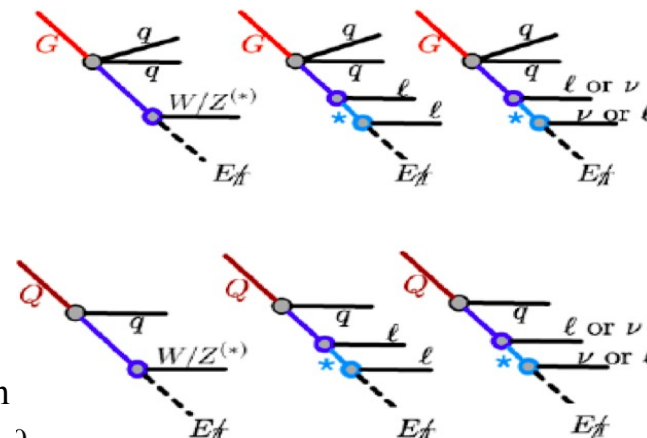
0-lepton + jets + E_T^{miss}



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

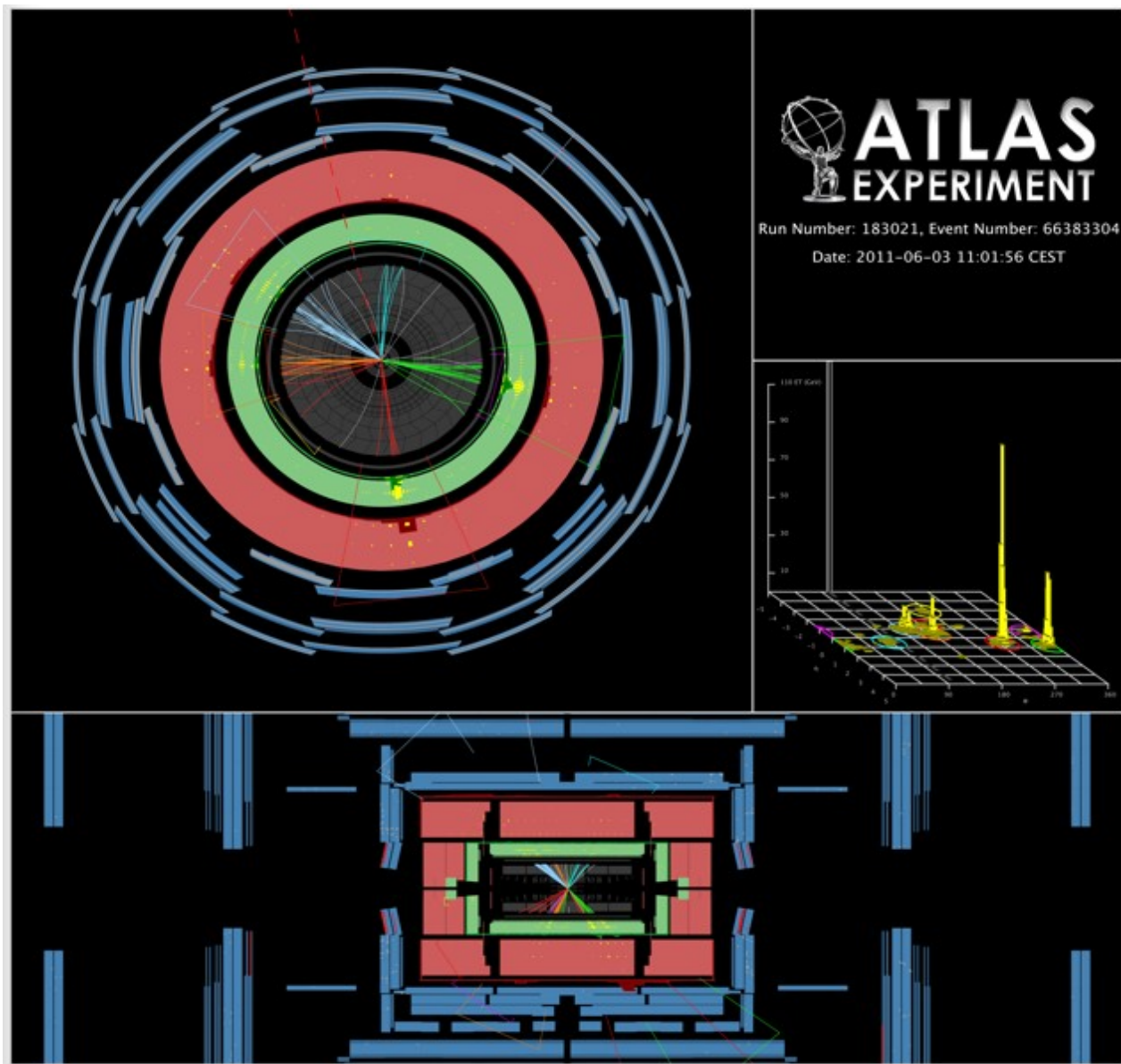


$$\tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$$





Search for squarks and gluinos with jets and MET



Event with 5 jets, $\text{met}=460$ GeV
and $m_{\text{eff}} = 1810$ GeV



Squark/gluino with jets+MET

➤ Main observable

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

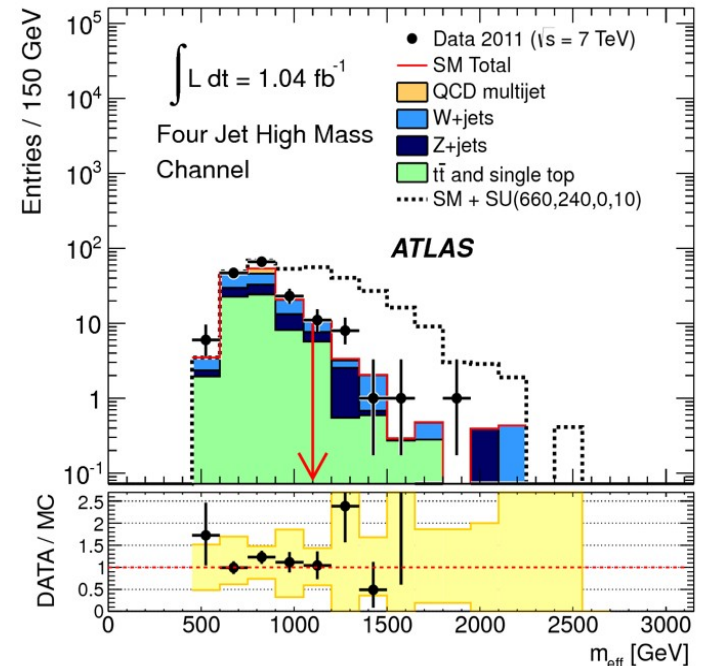
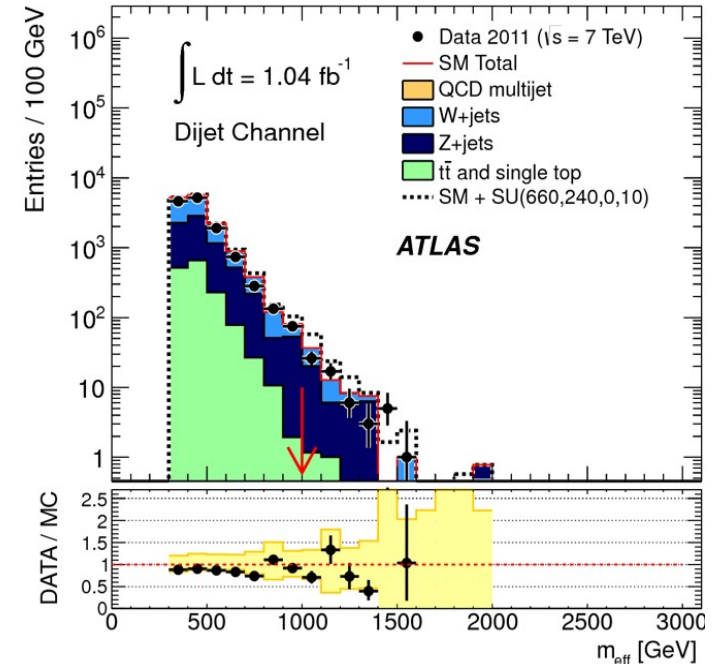
➤ Event Selection

0 lepton

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

➤ Main backgrounds

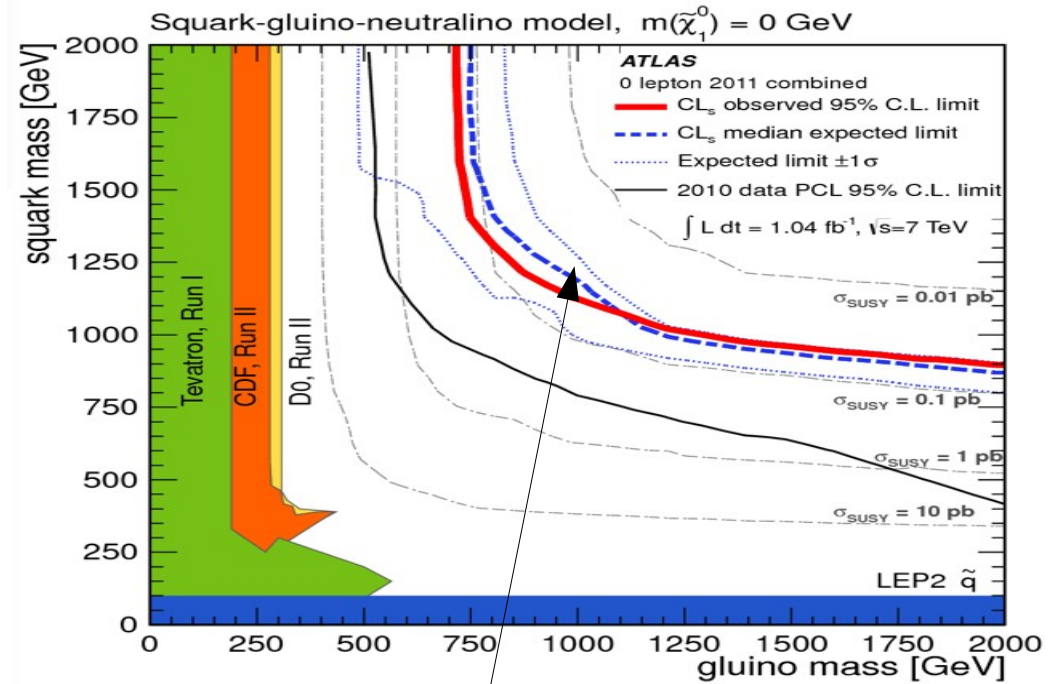
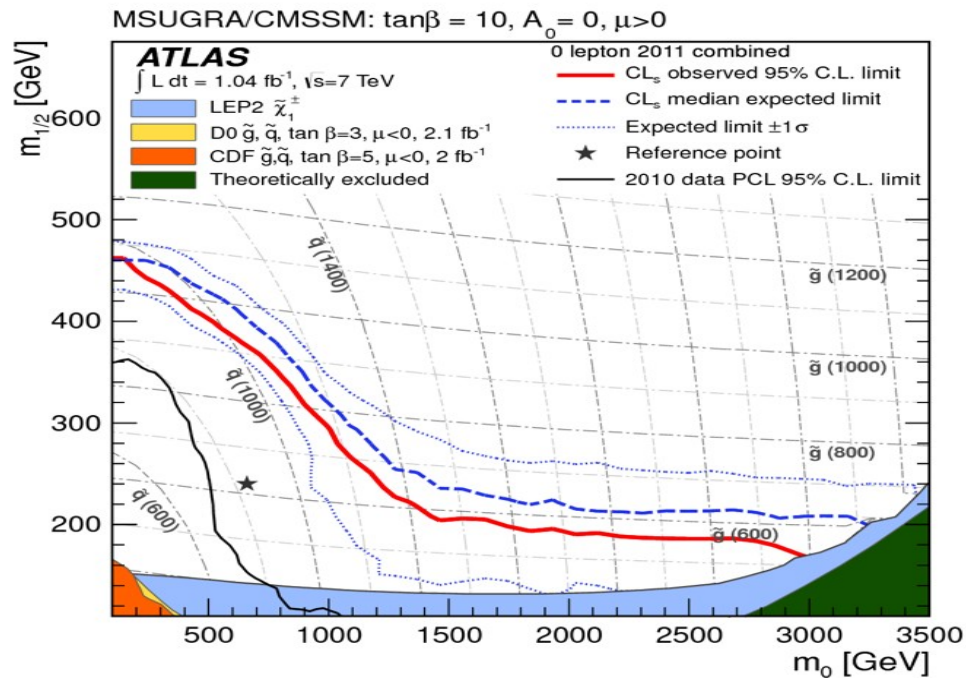
- W/Z+jets, top pair and single top





Squark/gluino with jets+MET

Limits in m_0 , $m_{1/2}$ plan
for mSUGRA/CMSSM



Simplified model with $m_{\text{LSP}} = 0$.
All other particles are at 5 TeV
Limits on squark/gluino up to 1 TeV



Squark/gluino: multijets analysis

- Main observable

$$E_T^{\text{miss}} / \sqrt{H_T}$$

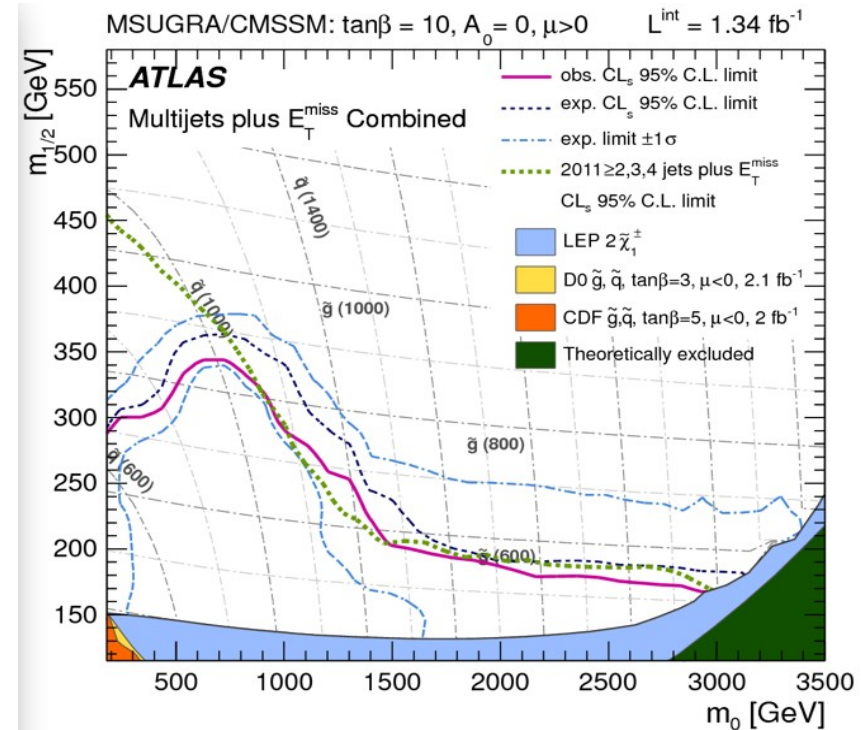
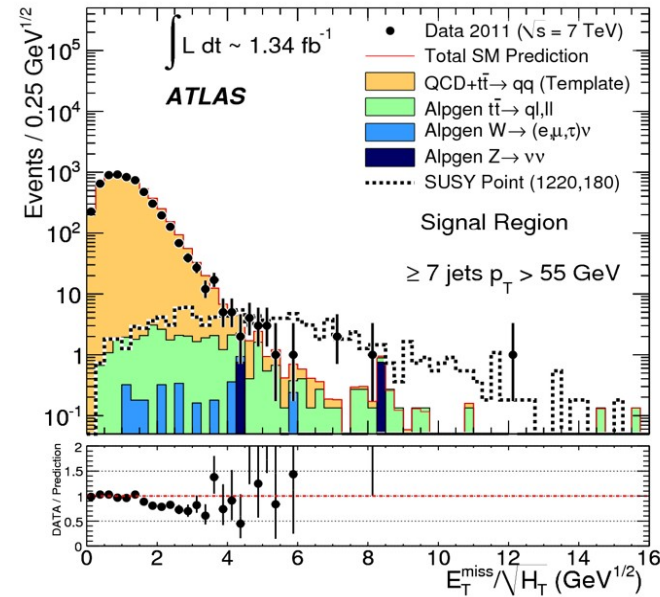
H_T : scalar sum of jets p_T

- Event Selection

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
$E_{\text{T}}^{\text{miss}} / \sqrt{H_T}$	> 3.5 GeV ^{1/2}			

- Main backgrounds

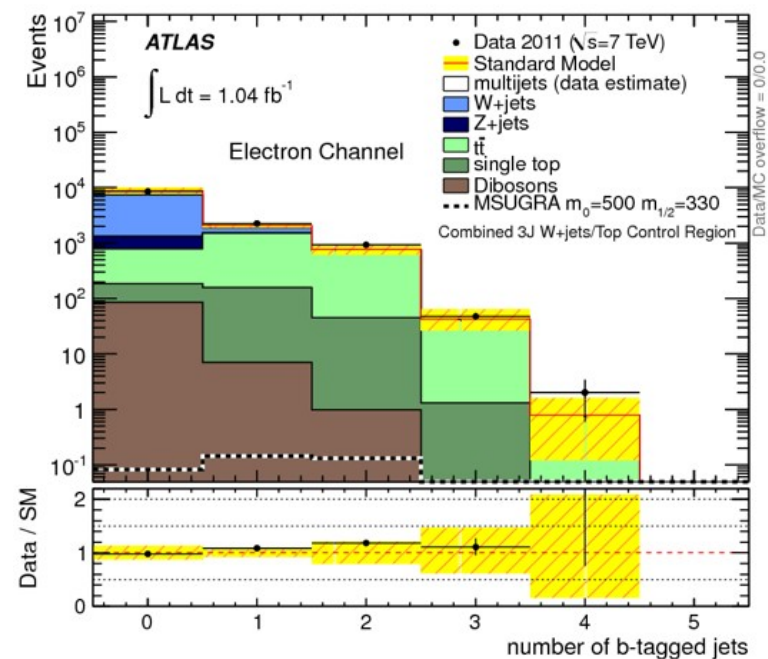
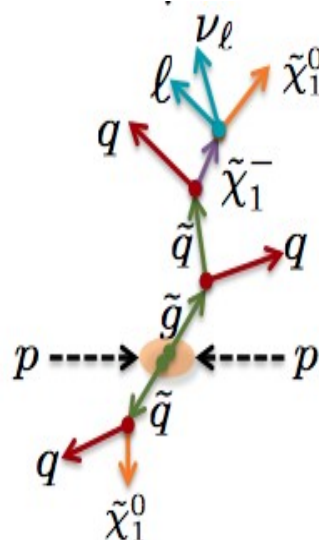
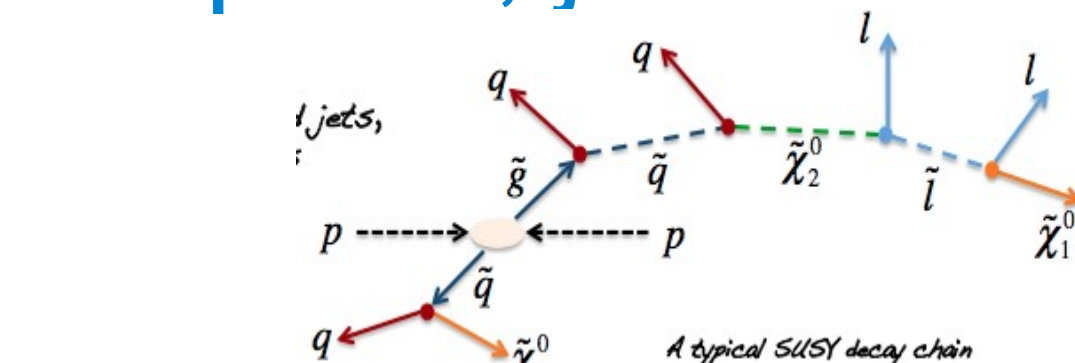
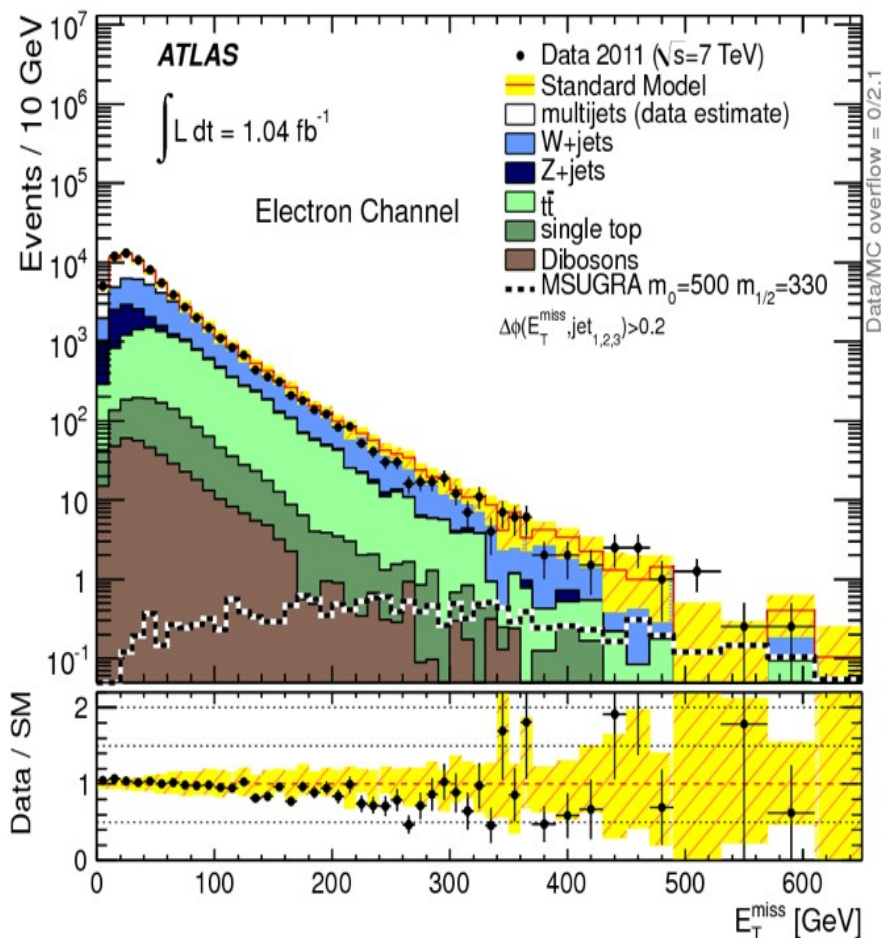
Multijet, hadronic and leptonic $t\bar{t}$ decay, W/Z+jets





Squark/gluino 1-lepton, jets+MET

3 or 4 jets, 1 lepton
Large E_T^{miss}

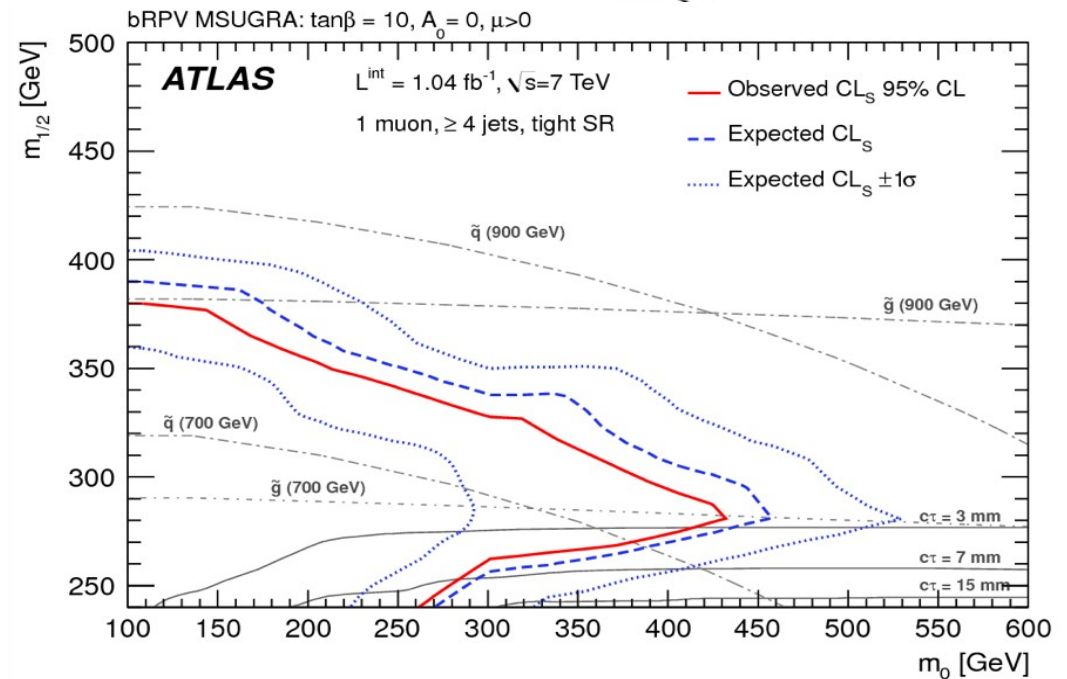
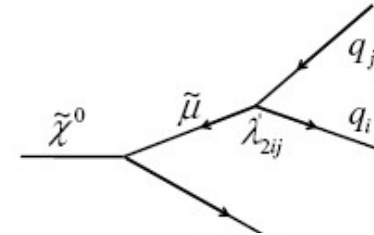
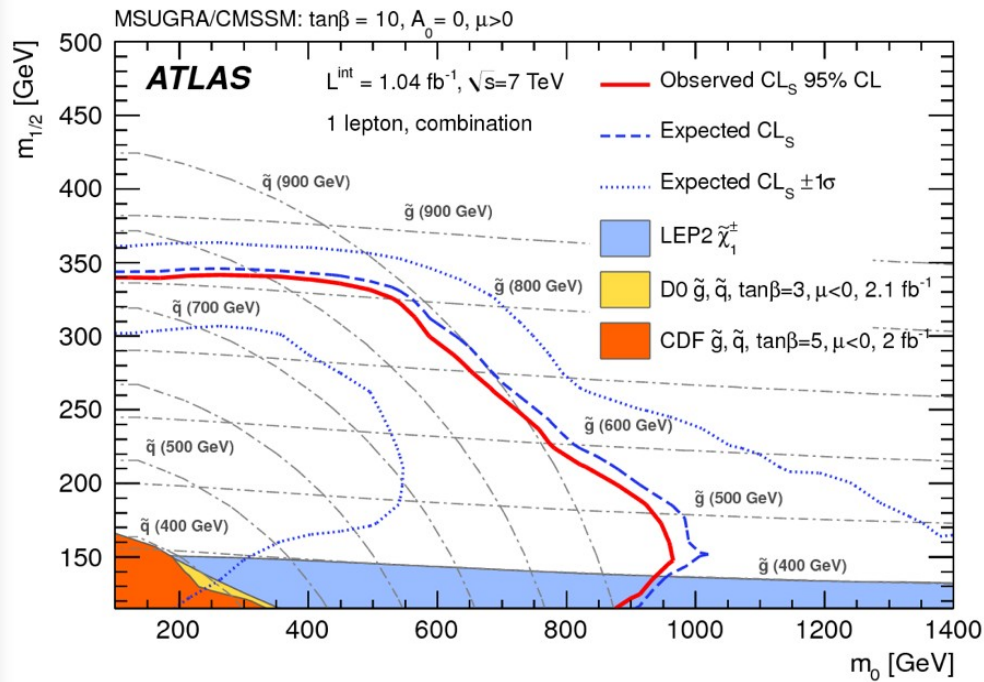




Squark/gluino 1-lepton, jets+MET

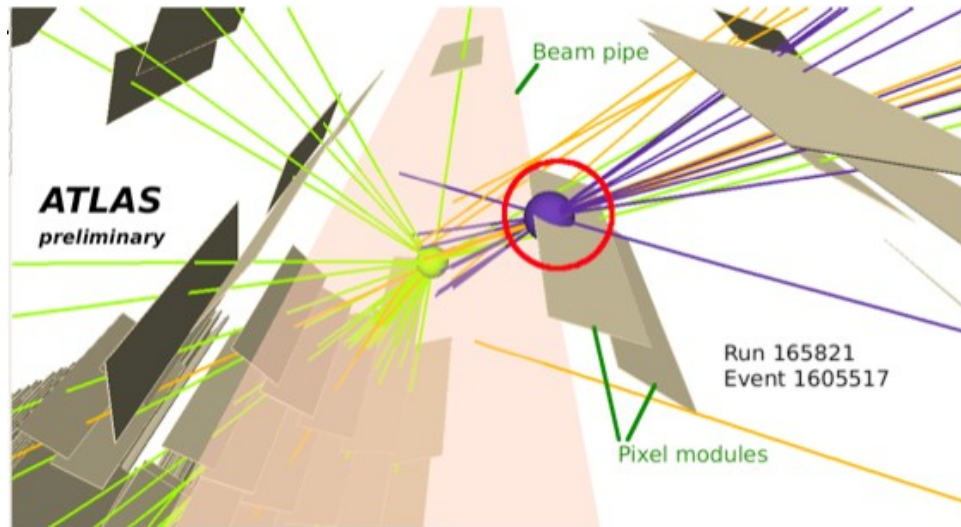
Limits in m_0 , $m_{1/2}$ plan
for mSUGRA/CMSSM

Bilinear R-Parity violation
Neutralino decays into lepton and 2
jets
Optimized 1-lepton analysis for bRPV

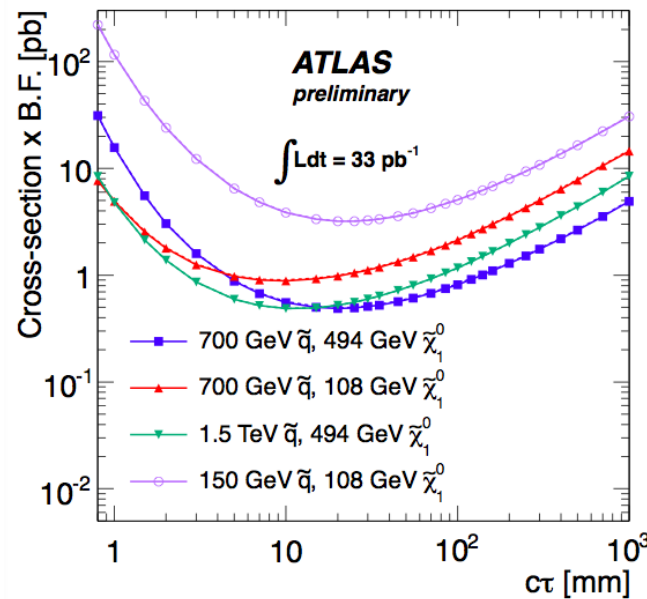
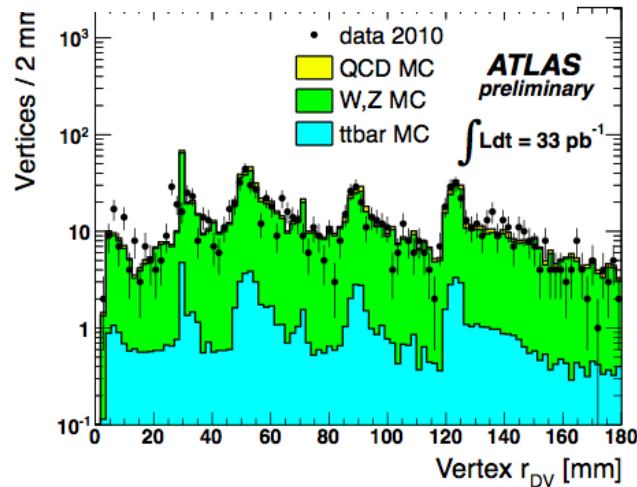
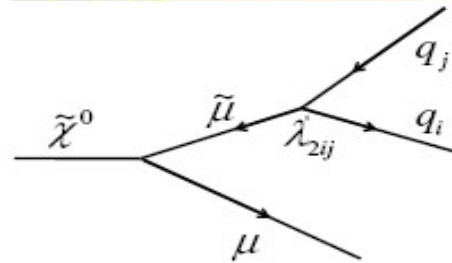




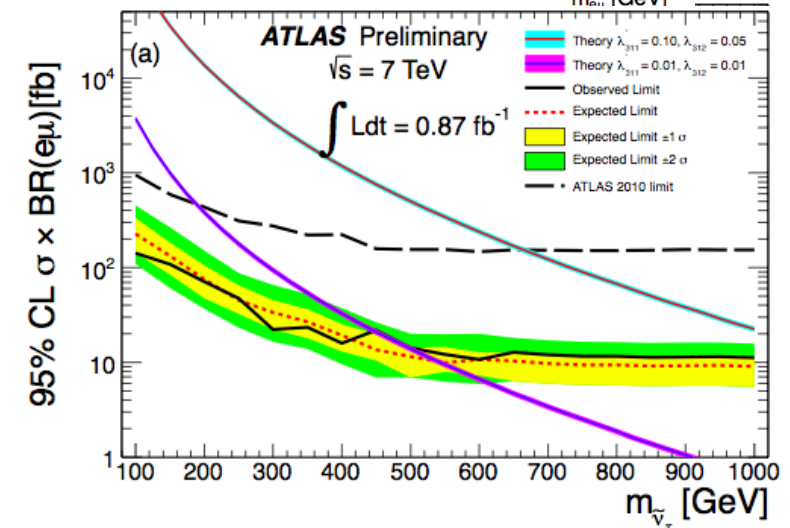
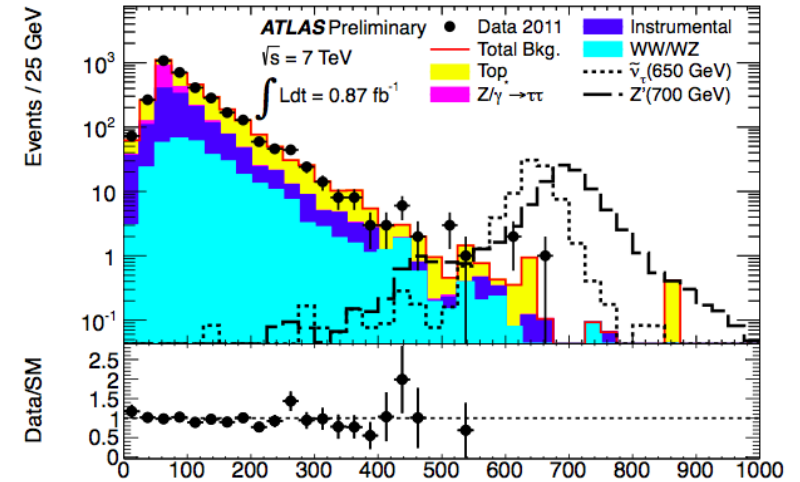
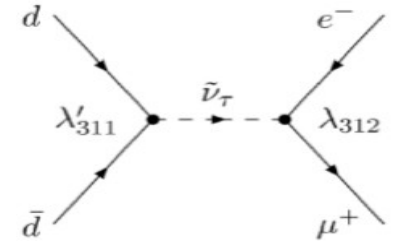
More RPV scenarios



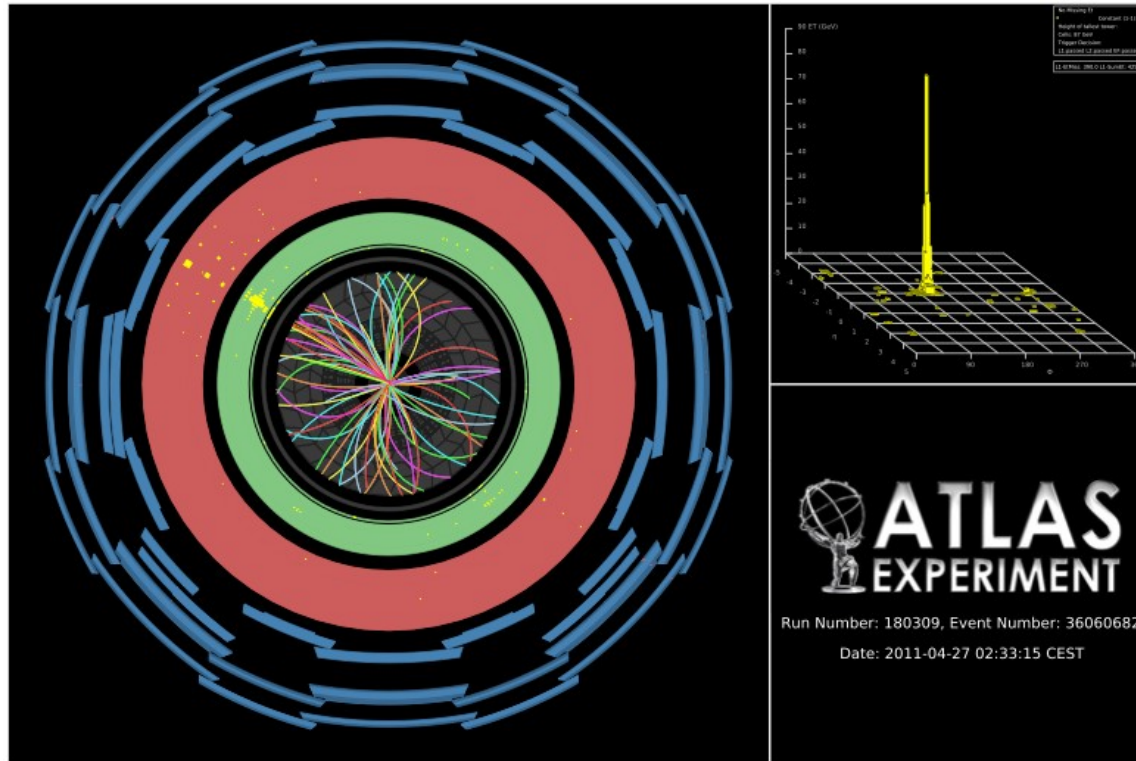
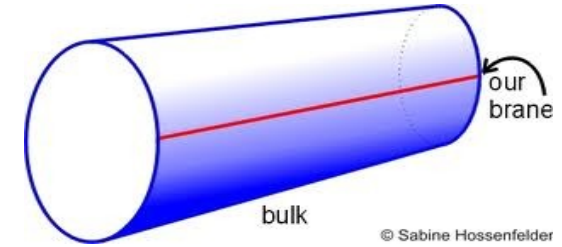
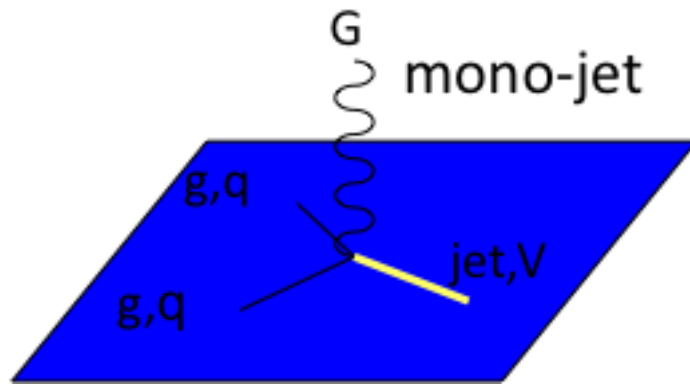
Displaced vertex



e-mu
resonance



Monojet + missing Et

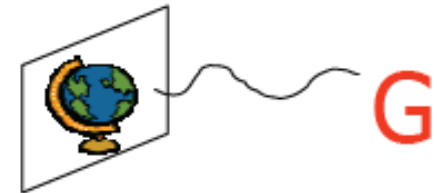


pt=602 GeV; eta=-1; phi=2.6
Missing Et = 523 GeV

ADD

Arkani-Hamed, Dimopoulos, Dvali,
Phys Lett B429 (98)

Many large compactified EDs
In which G can propagate



$$M_{Pl}^2 \sim R^n M_{Pl(4+n)}^{(2+n)}$$

Effective $M_{Pl} \sim 1\text{TeV} \rightarrow$ if
compact space (R^n) is large



Monojet+MET final states

Observable

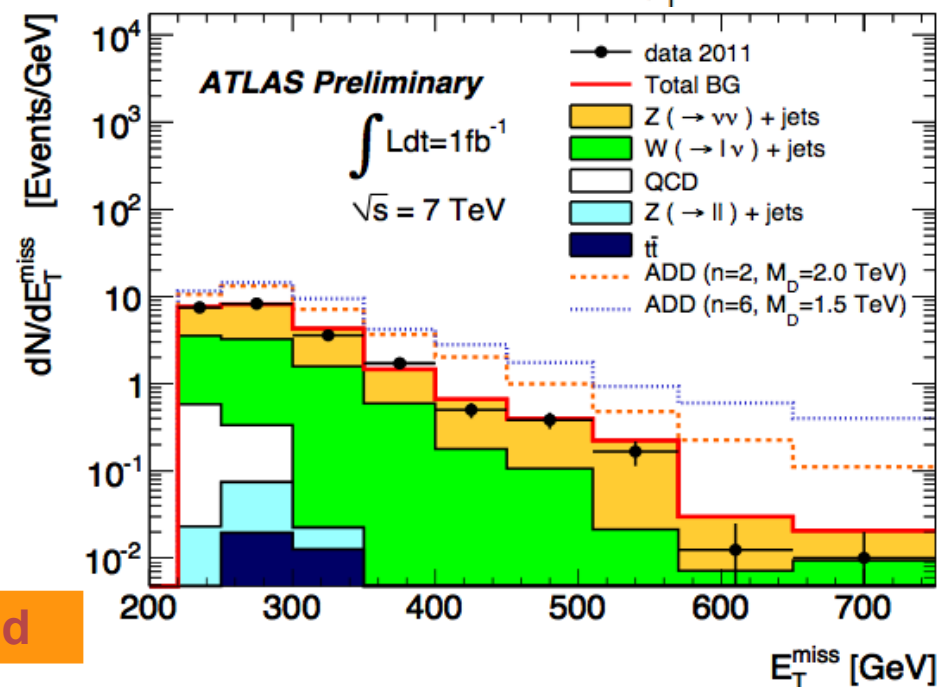
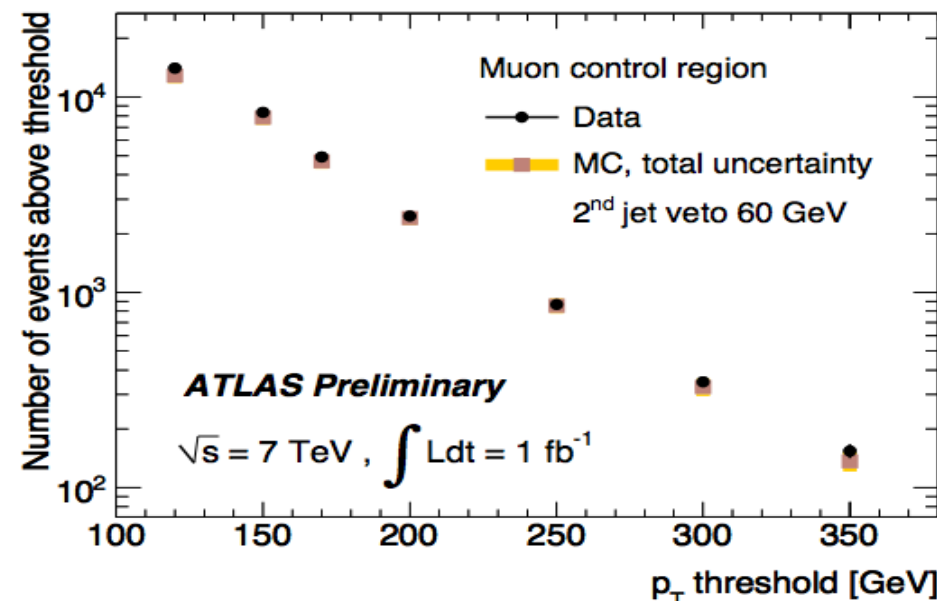
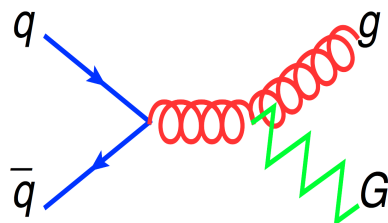
- Large missing E_T
- High p_T jet

Event Selection

- High p_T jet and large MET
- No second jet above threshold
- No reconstructed lepton (e, μ)

Main background

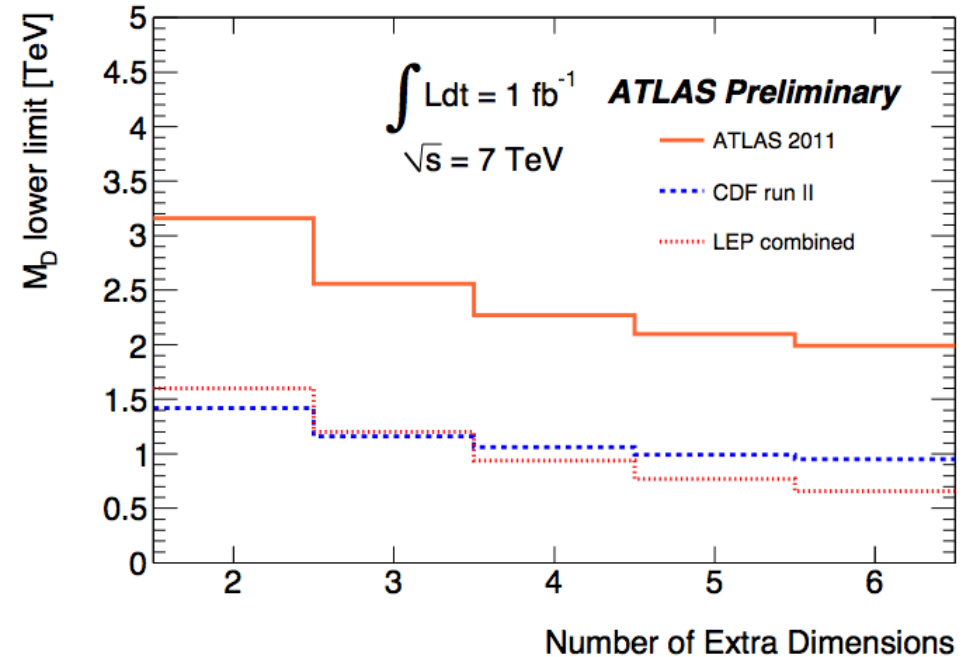
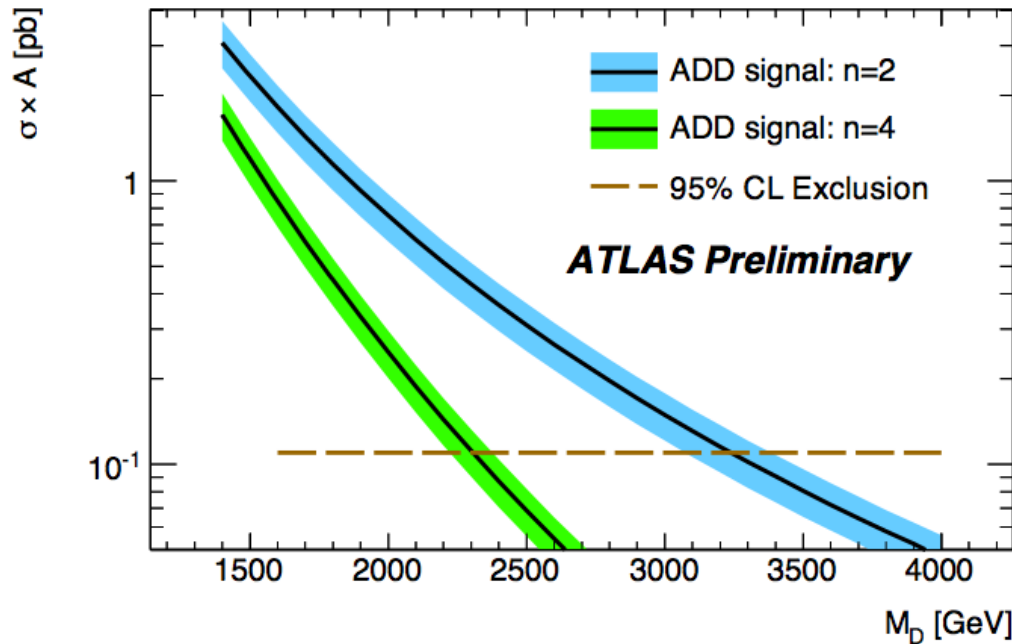
- EW SM (Z/W +jets)





Monojet+MET final states

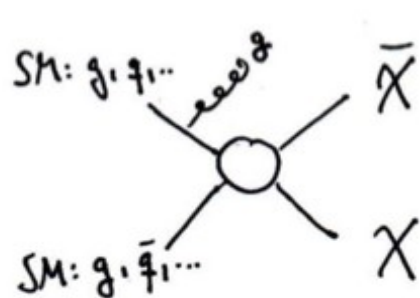
$$\sigma \sim 1/(M_D)^{2+n}$$



No evidence for new physics signal found
Observed (Expected) 95% C.L. Limits (2011 data)
ADD graviton $M_D > 3.16$ to 1.99 (2.98 to 1.92) TeV for $n=2$ to 6



Limits on WIMPS



Effective Theory
Contact operators e.g. vector coupling:

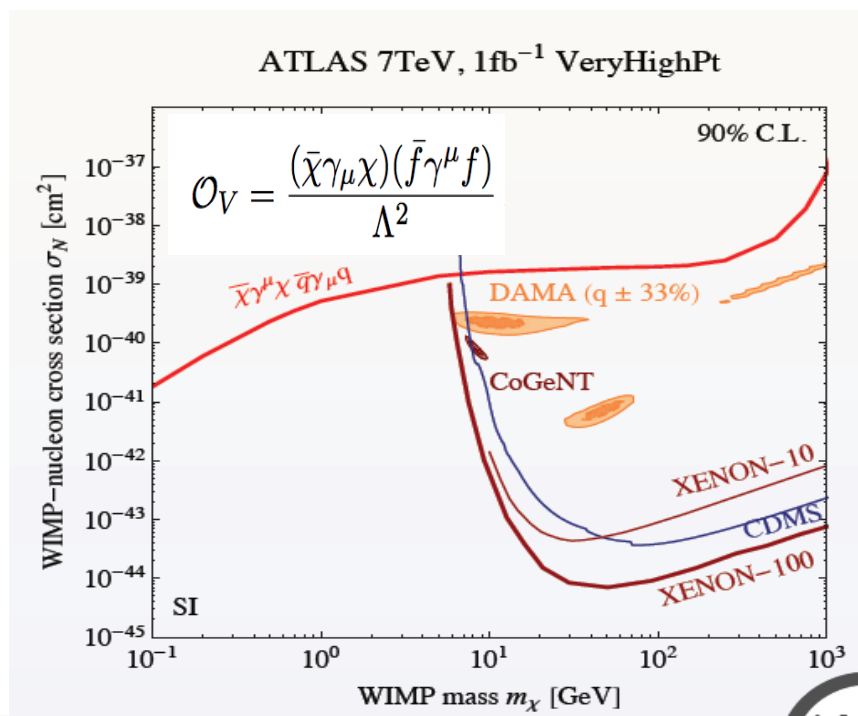
$$\mathcal{O}_V = \frac{(\bar{\chi} \gamma_\mu \chi)(\bar{f} \gamma^\mu f)}{\Lambda^2}$$

Two groups of theorists at Fermilab and UCI

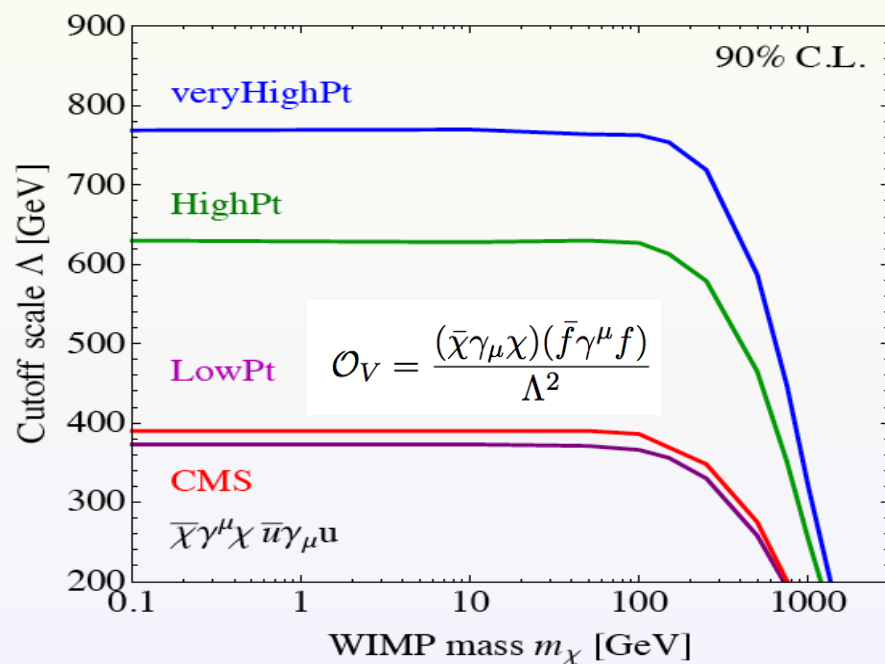
Latest papers by them on our 1fb^{-1} result:

arxiv:1109.4398 (FNAL)

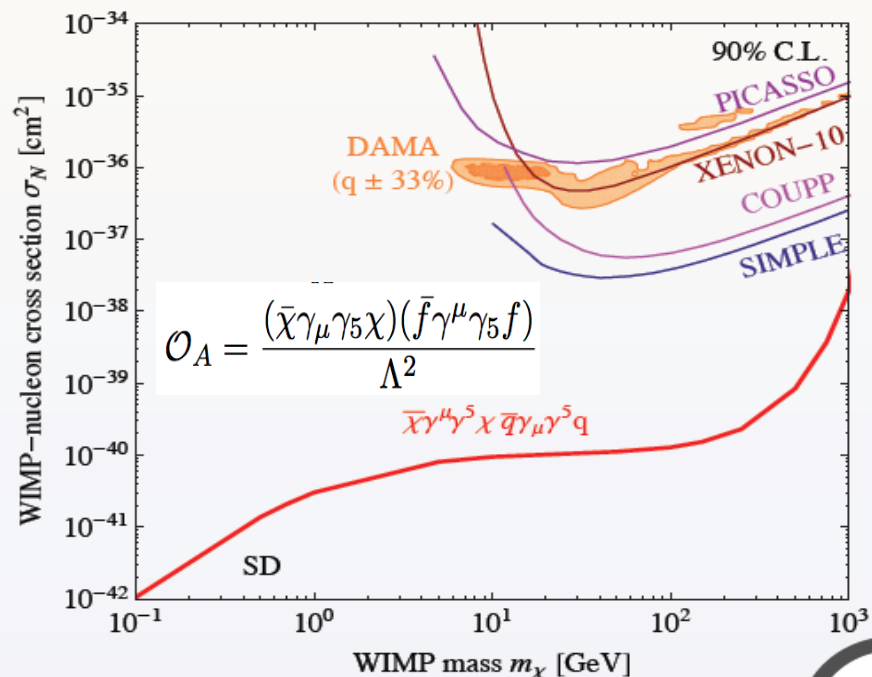
arxiv:1108.1196 (UCI)



ATLAS 7 TeV , 1fb^{-1}



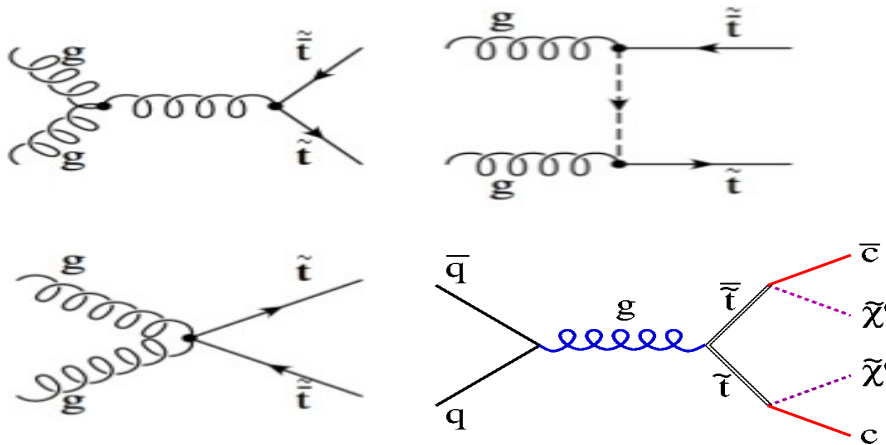
ATLAS 7TeV, 1fb^{-1} VeryHighPt





More monojet interpretations...

Stop/sbottom – neutralino
nearly degenerated

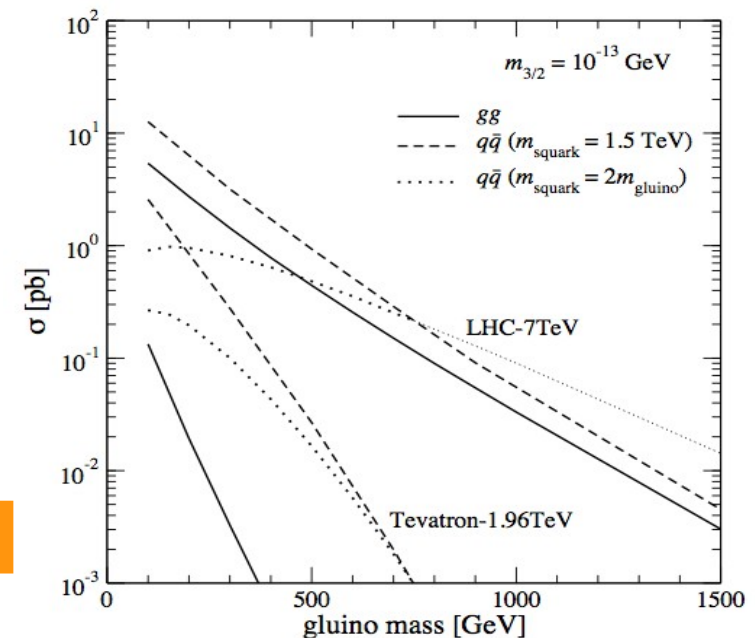
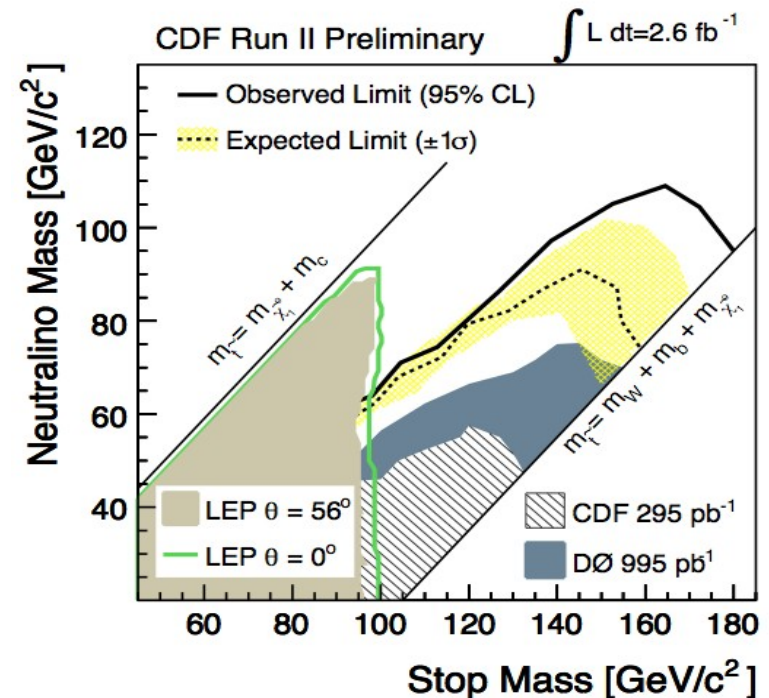


gluino-squark/gravitino production
LSP=gravitino, NLSP=gluino
GMSB, Split SUSY

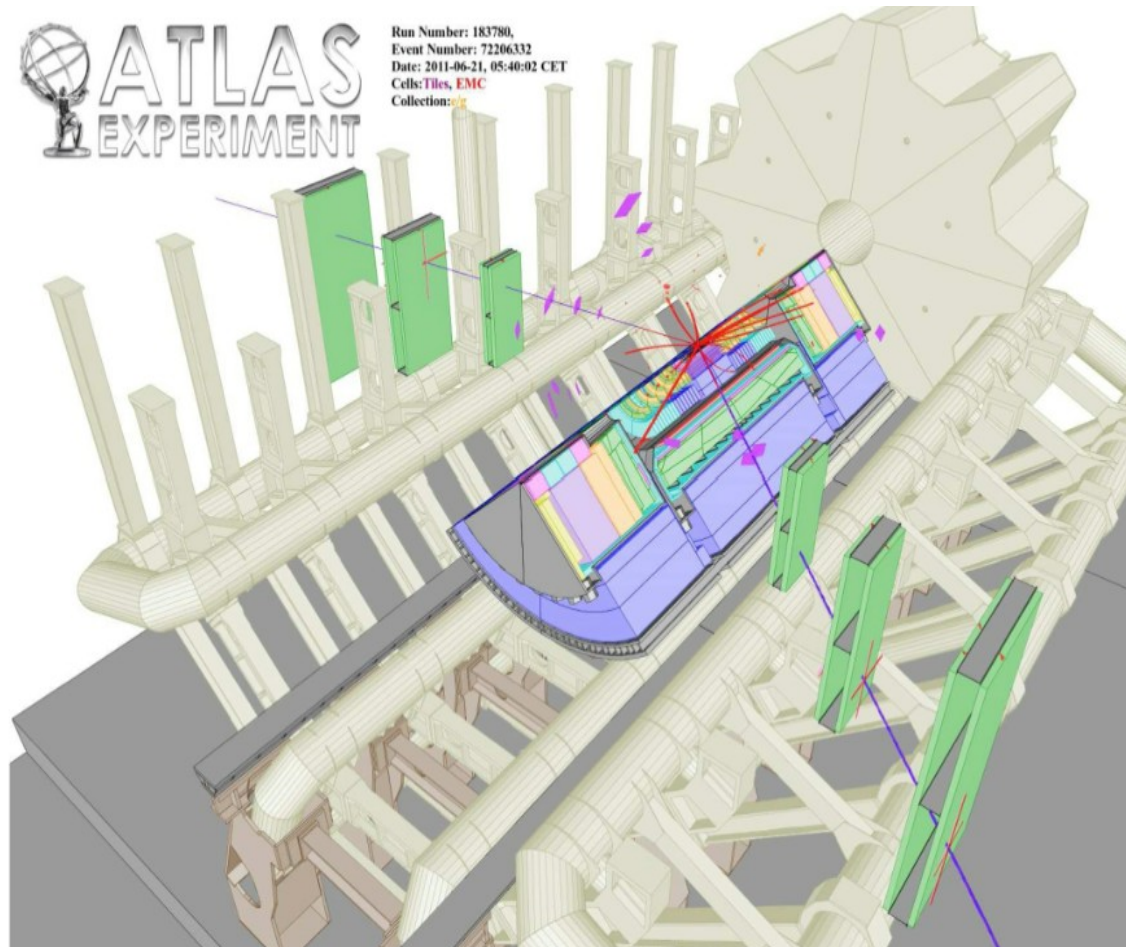
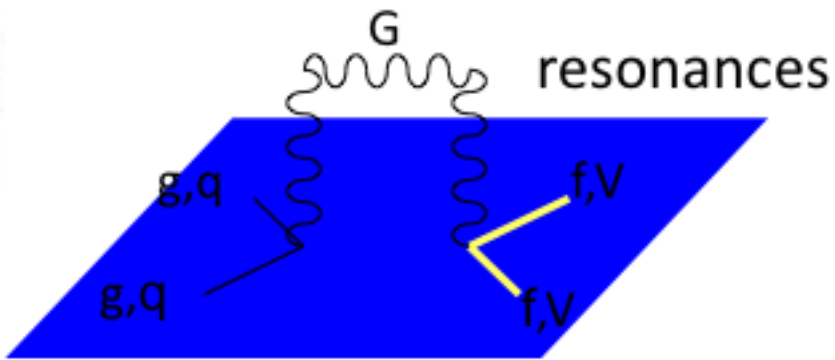
$$q + g \rightarrow \tilde{q} + \tilde{G} \quad \text{and} \quad \bar{q} + g \rightarrow \tilde{\bar{q}} + \tilde{G}$$

$$g + g \rightarrow \tilde{g} + \tilde{G}$$

Aiming for Moriond 2012 with 5 fb-1



Dilepton final states



RS
Randall, Sundrum,
 Phys Rev Lett 83 (99)

1 highly curved ED
Gravity localised in the ED

Planck TeV brane

$$\Lambda_\pi = \bar{M}_{pl} e^{-kR_c\pi}$$

$$\Lambda_\pi \sim \text{TeV}$$

if warp factor $kR_c \sim 11-12$
 k/M_{pl} , k : curvature scale

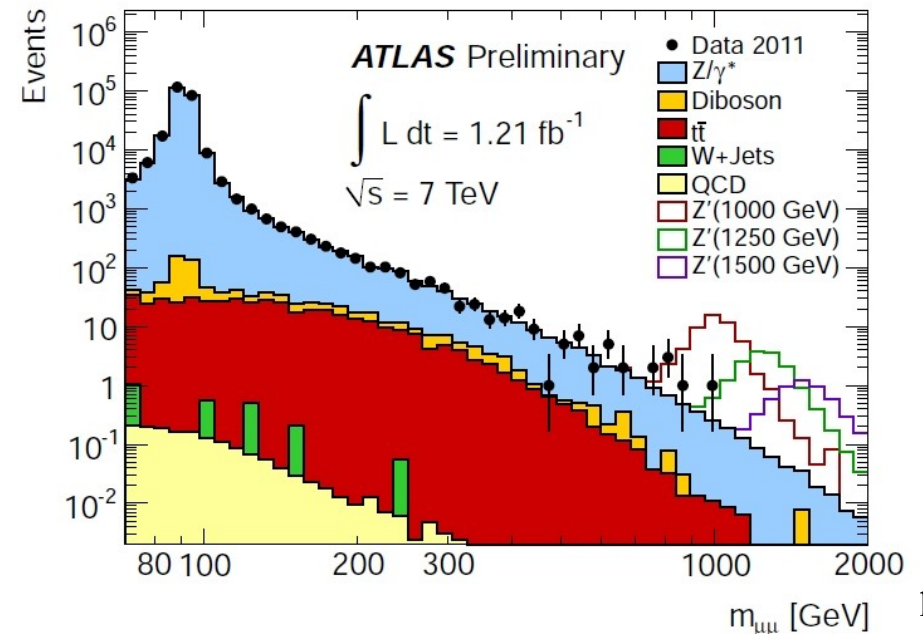
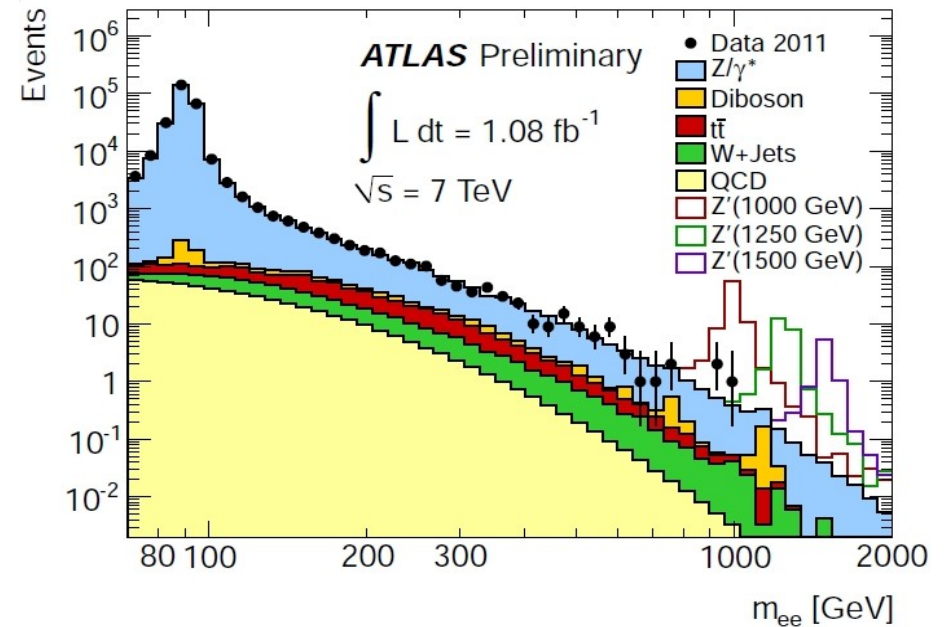
$$m_T = 959 \text{ GeV}$$



Dilepton final states

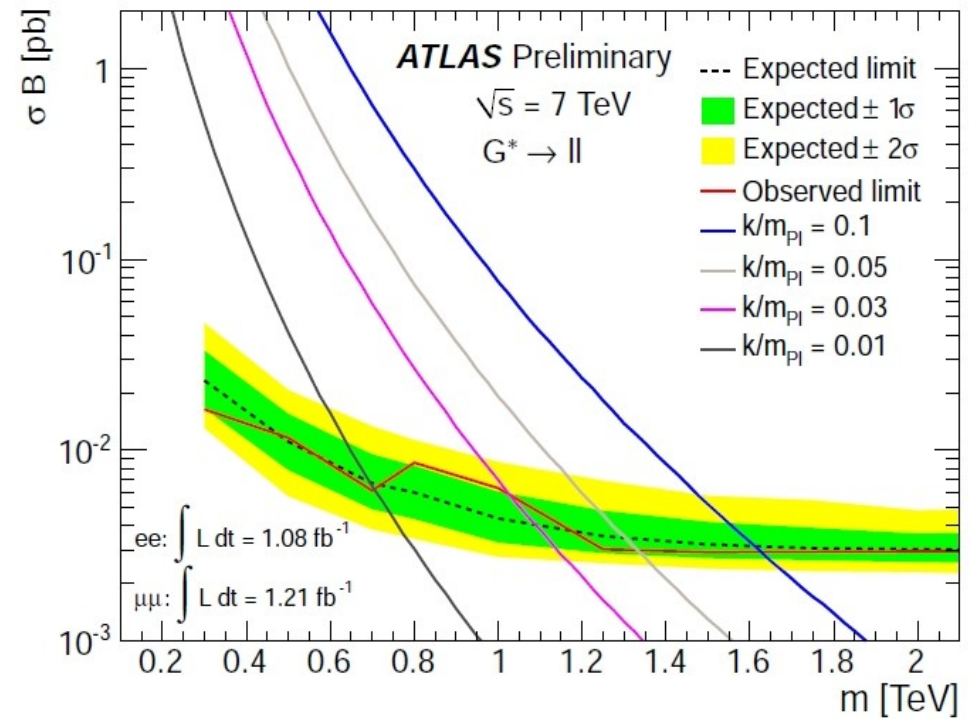
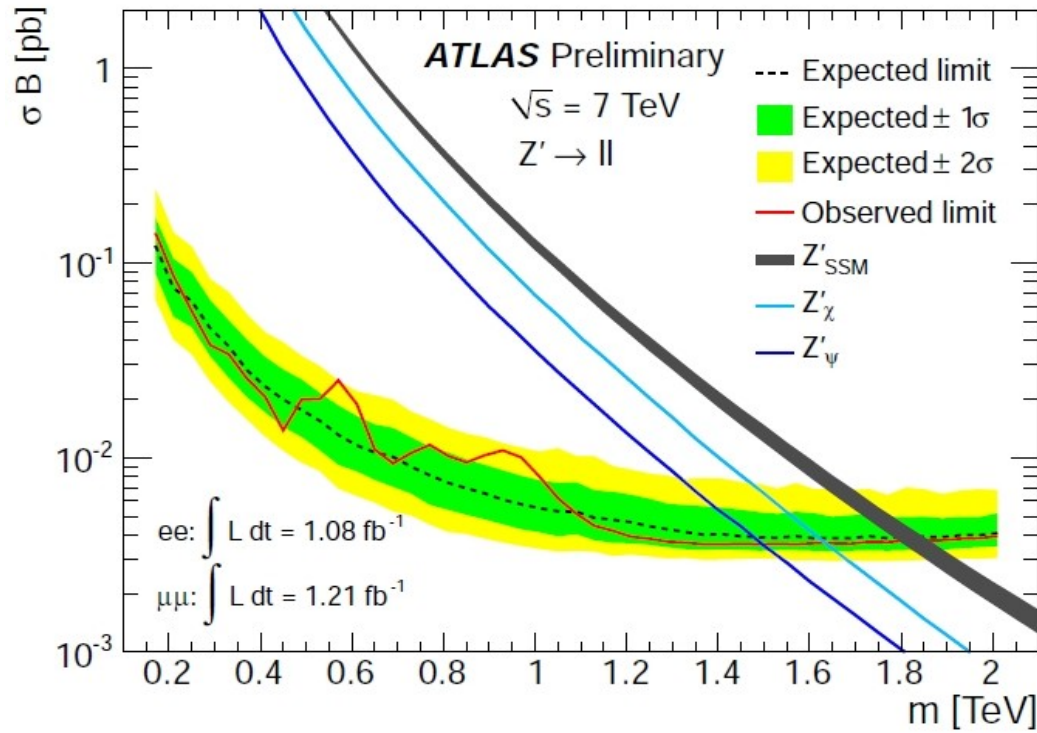
Z' (SSM, E6)
Randall-Sundrum Graviton

- Observable
 - Dilepton invariant mass
- Event Selection
 - Two leptons (same flavor, e or μ)
- Main background
 - SM EW background ($Z/\gamma^* \rightarrow \ell\ell$)





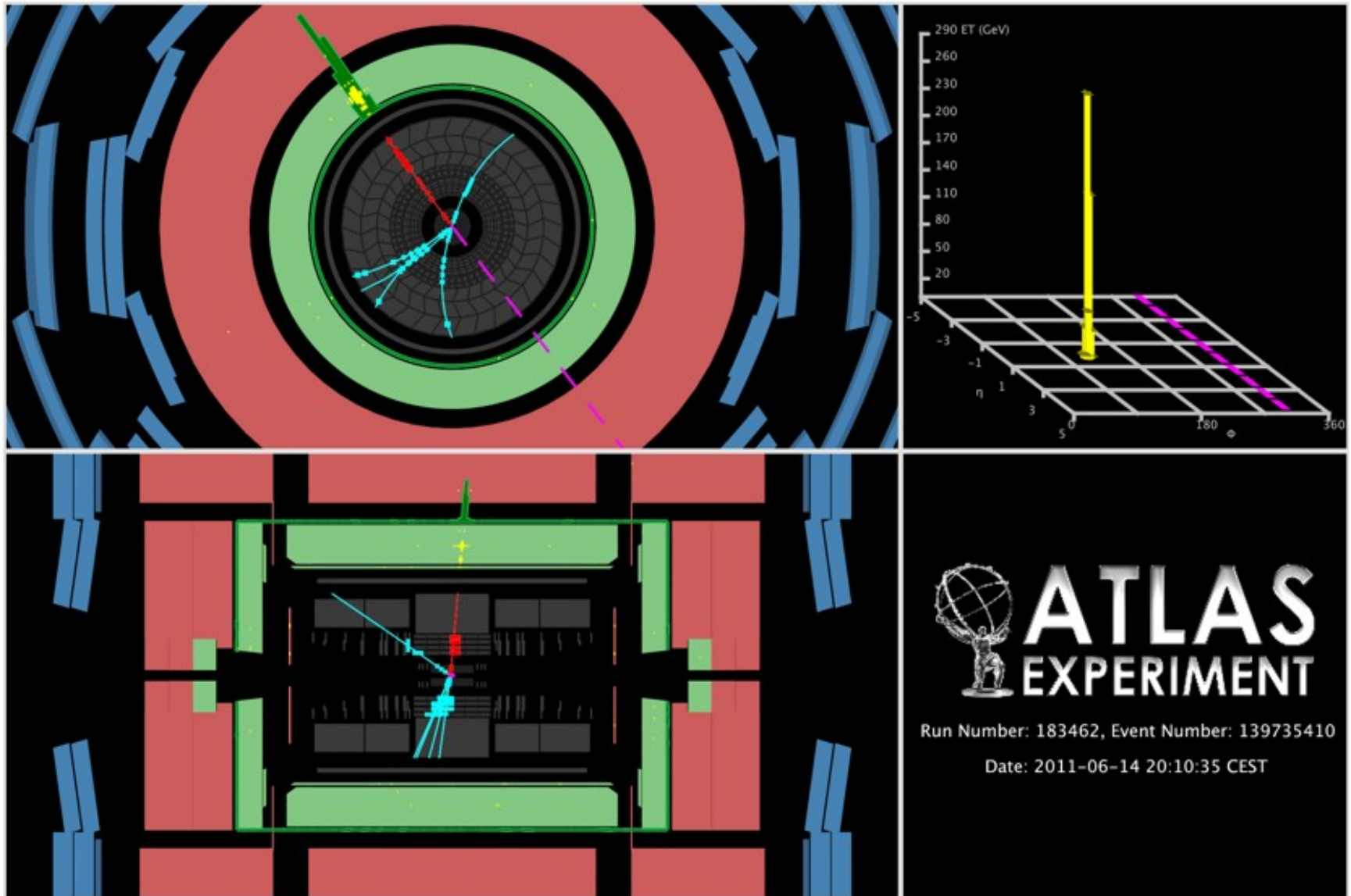
Dilepton final states



Observed (Expected) 95% C.L. Limits (2011 data)

E6 Z' bosons M in the range	1.50-1.64 (1.50-1.64) TeV
Z' SSM	$M > 1.83$ (1.83) TeV
RS G , $k/M=0.1$	$M > 1.63$ (1.61) TeV
RS G , $k/M=0.01$	$M > 0.7$ (0.7) TeV

Lepton+MET final states

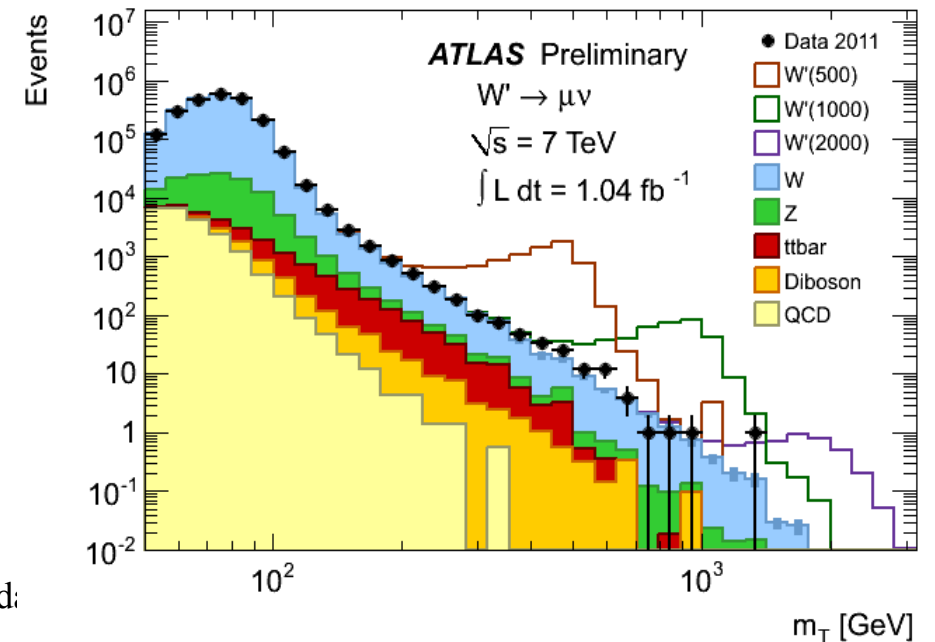
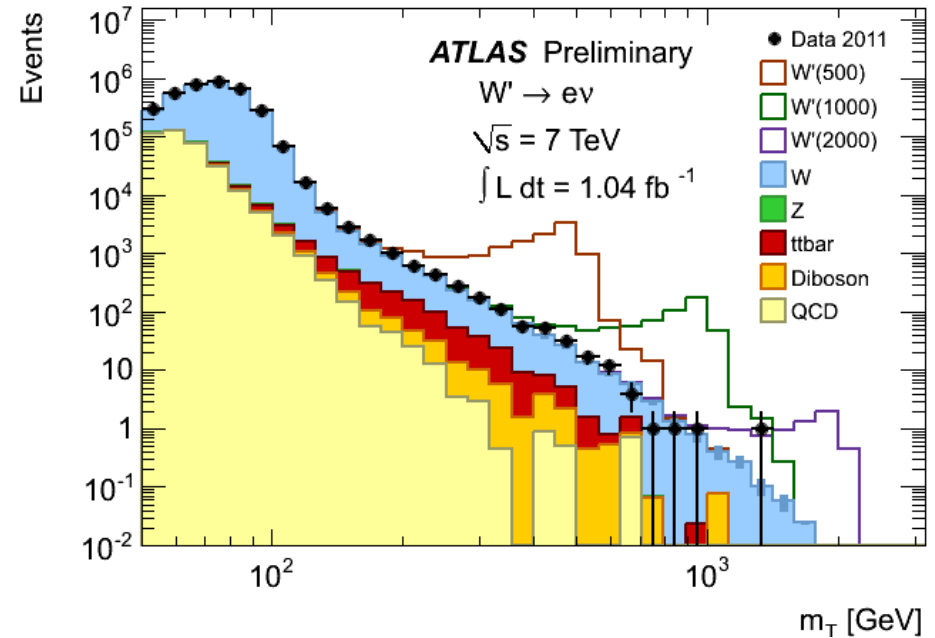


electron $p_T=668$ GeV



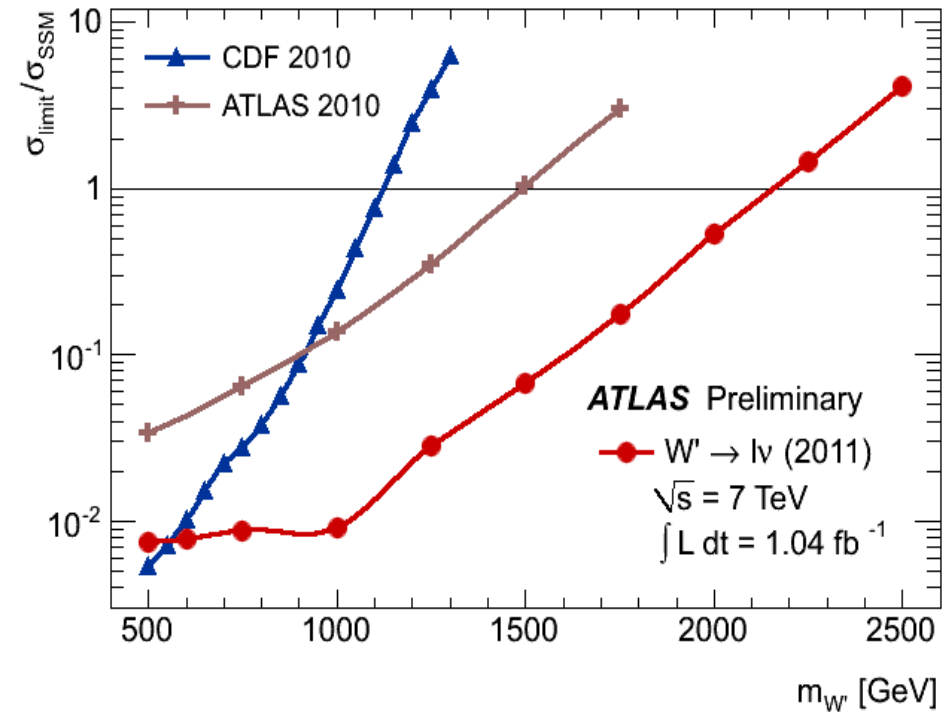
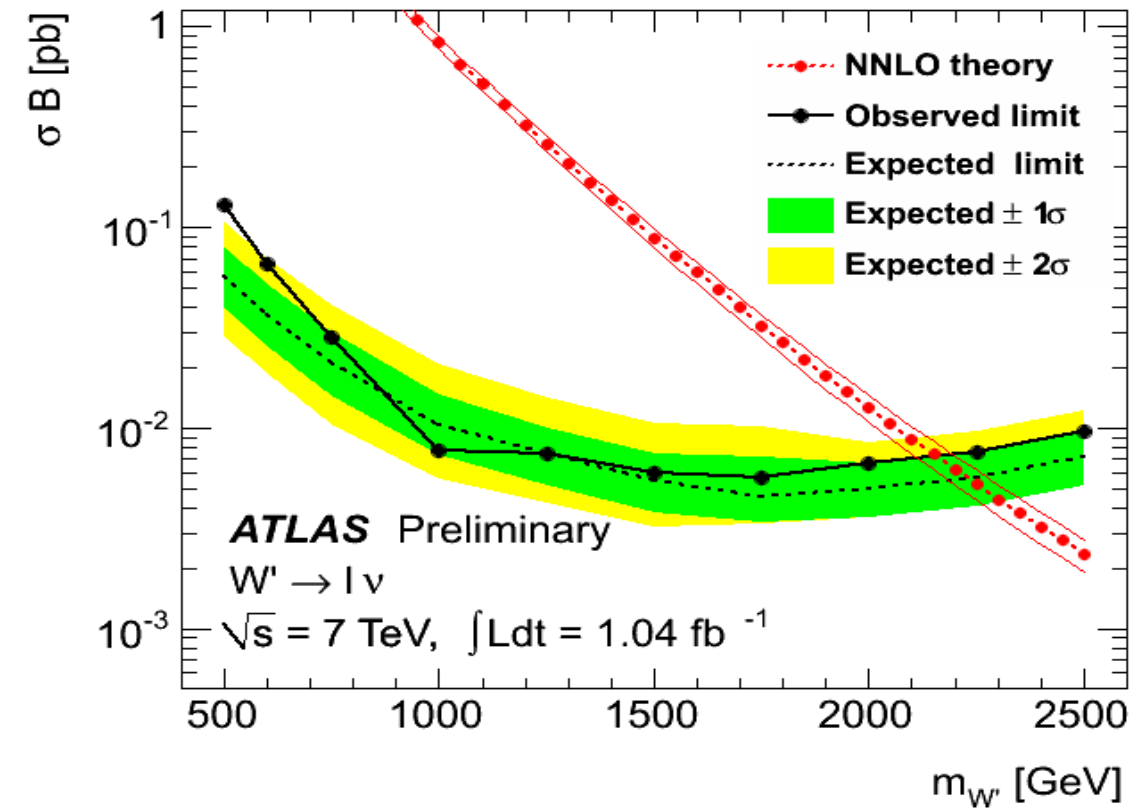
Lepton+MET, W'

- **Observable**
 - Transverse mass
- **Event Selection**
 - One high pt lepton (e, μ) and high MET
- **Background**
 - SM EW background (W)
 - QCD faking electron



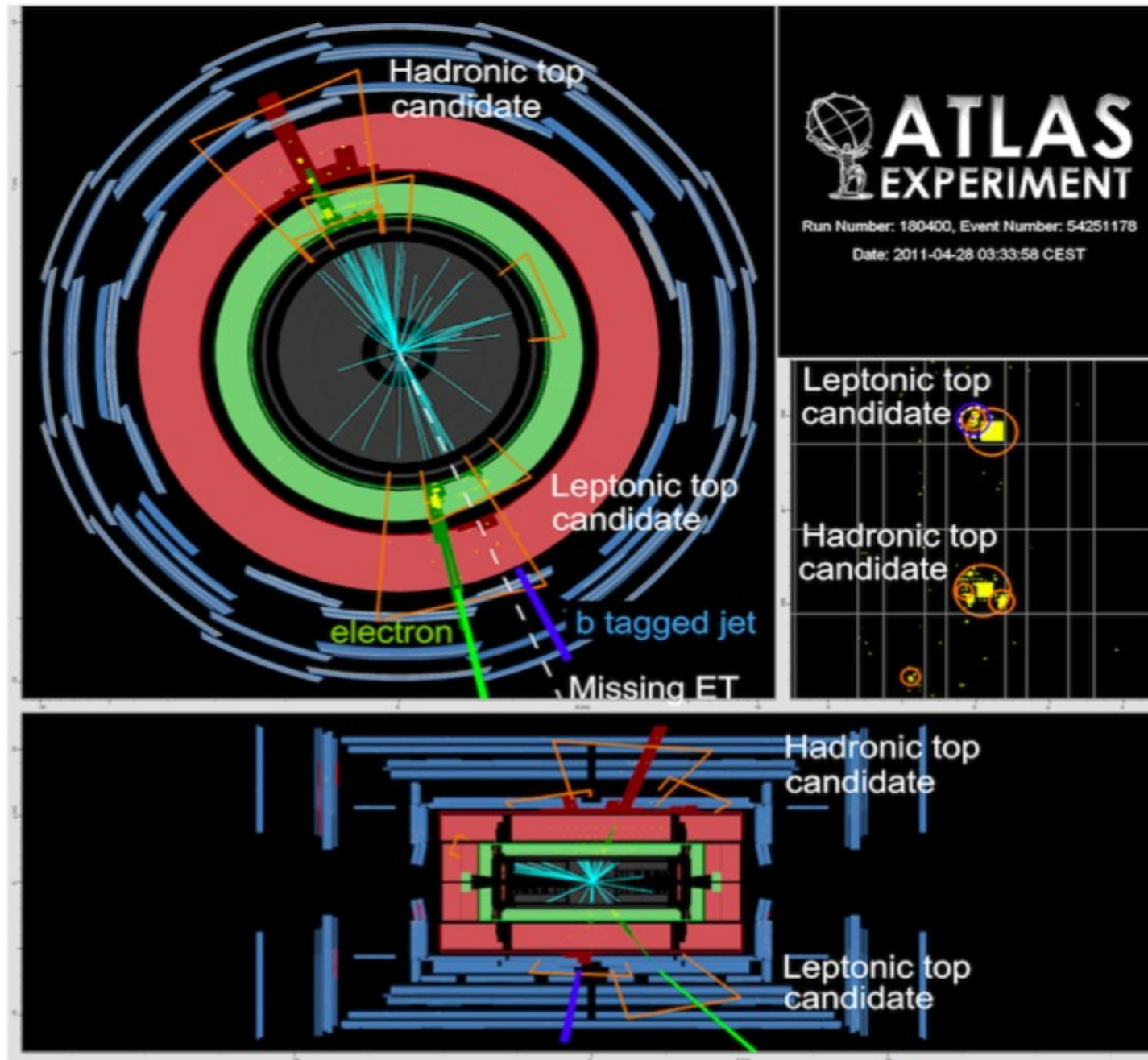


Lepton+MET, W'



No evidence for new physics signal found
 Observed (Expected) 95% C.L. Limits
 W' SSM $M > 2.23$ (2.15) TeV

Semileptonic $t\bar{t}$ final states





Semileptonic $t\bar{t}b\bar{a}$ final states

Kaluza-Klein gluon
leptophobic Z'

Observable

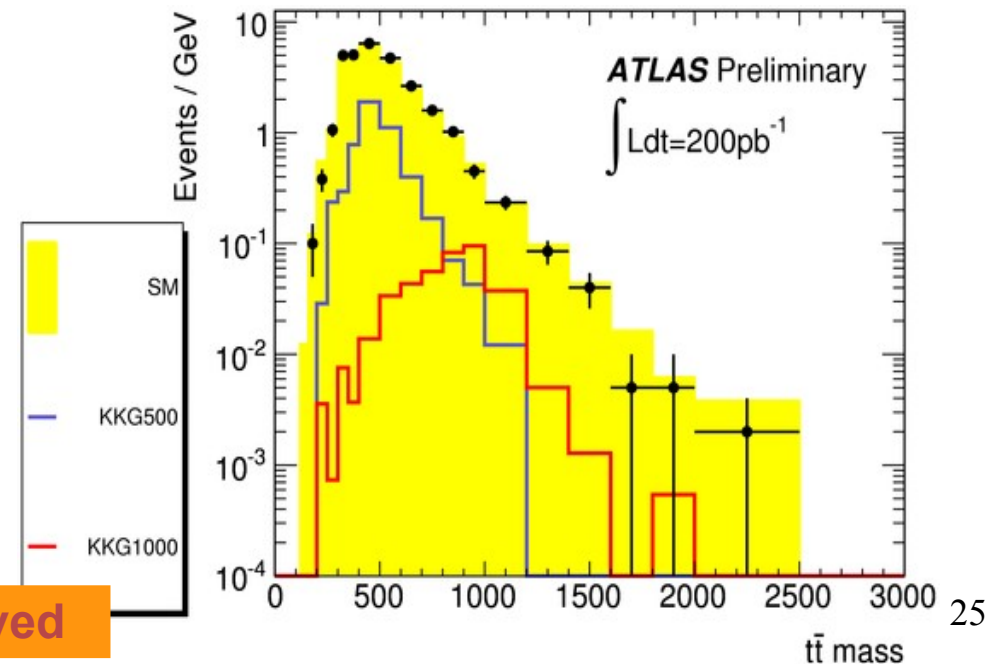
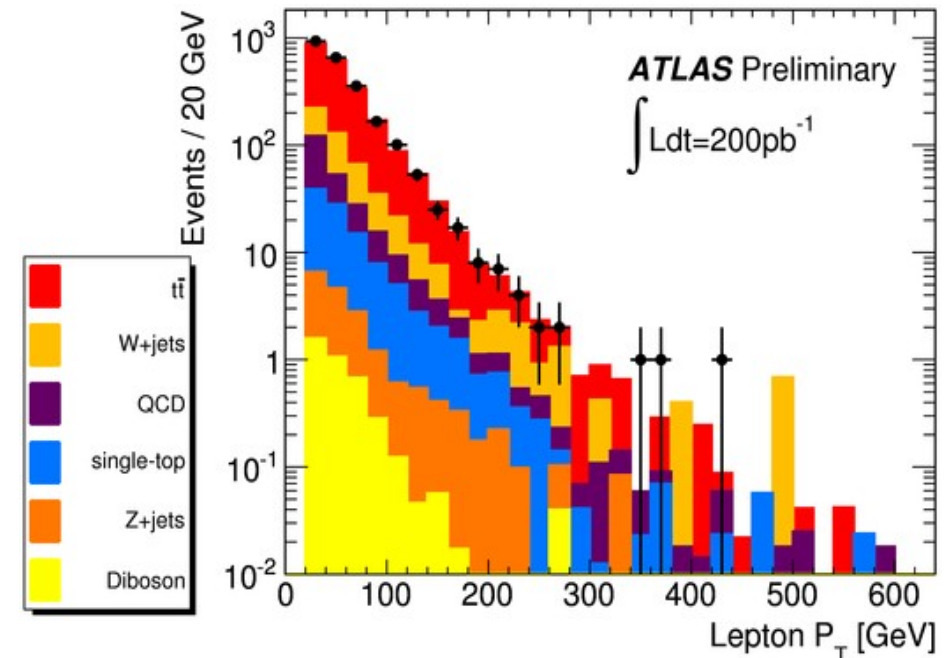
- Invariant mass of the jets, lepton and MET

Selection

- ≥ 4 jets
- ≥ 1 b-jet
- Just one lepton, $p_T > 20$ GeV
- Large MET

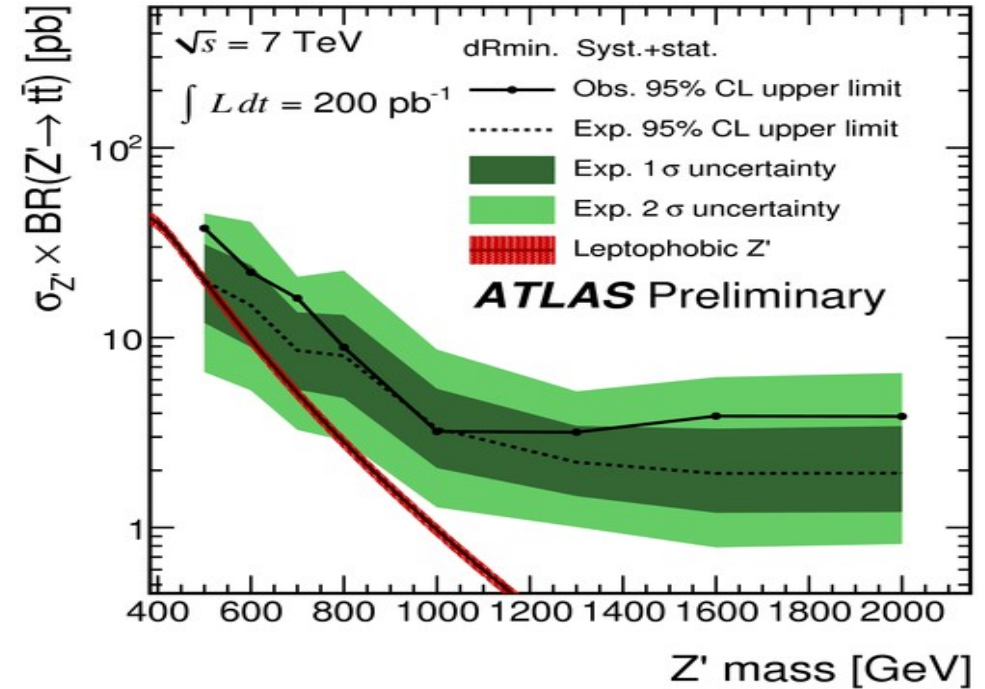
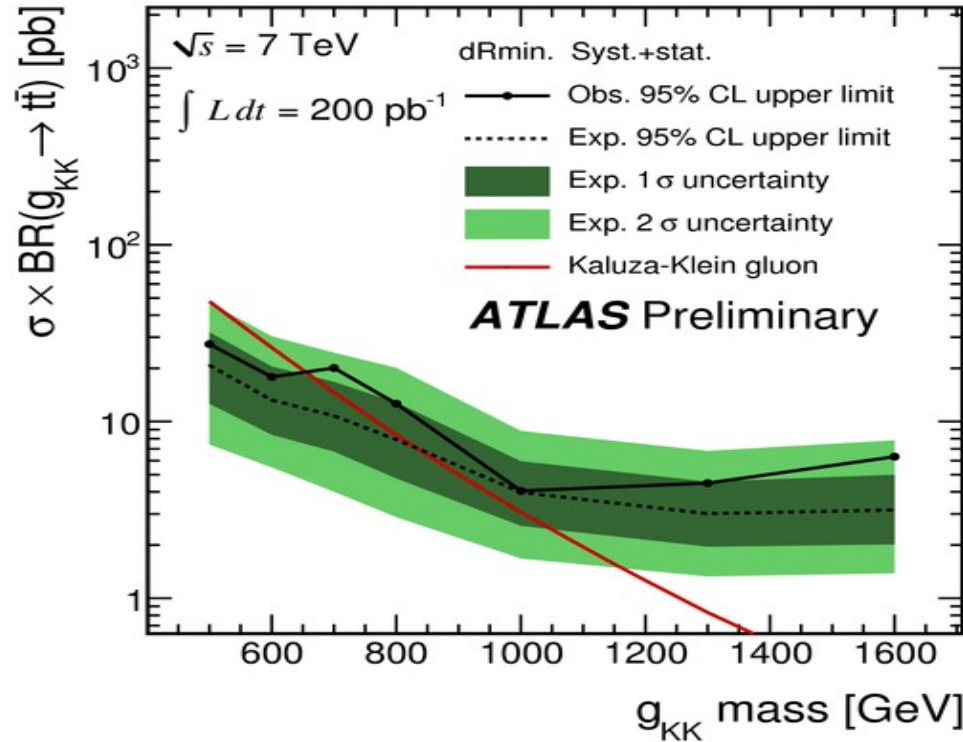
Background

- Main background SM $t\bar{t}b\bar{a}$





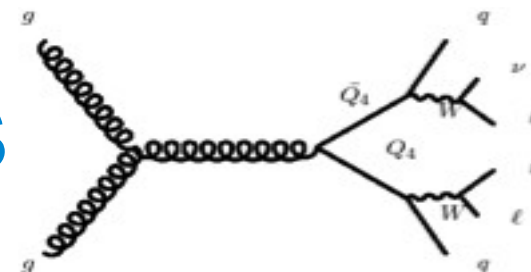
Semileptonic $t\bar{t}$ final states



Observed (Expected) 95% C.L. Limits
 KK-gluon $M > 650$ (825) GeV
 No exclusion limits on Z' TC2 Leptophobic

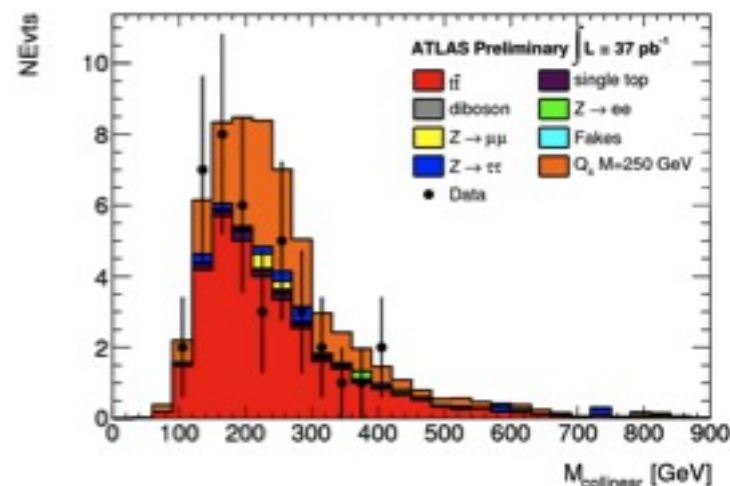
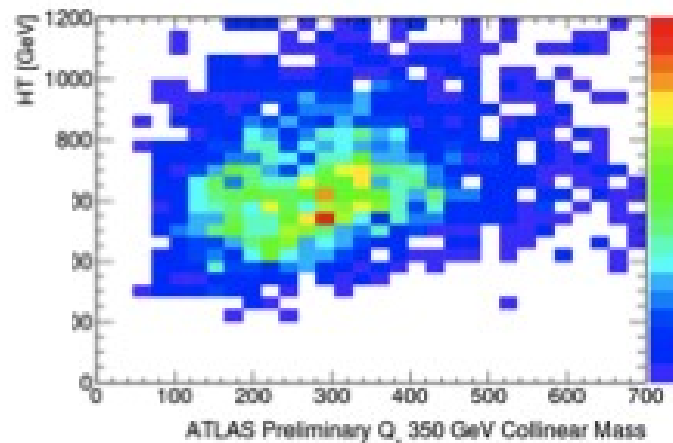
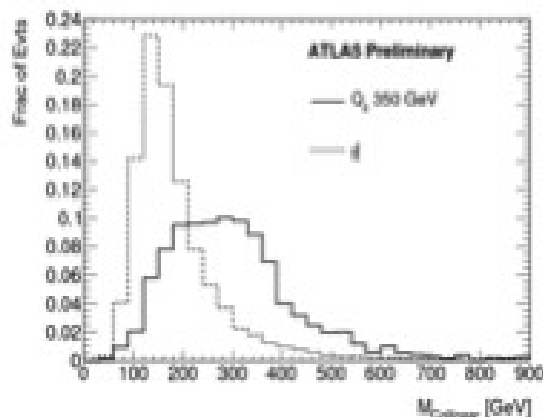


Fourth generation quarks

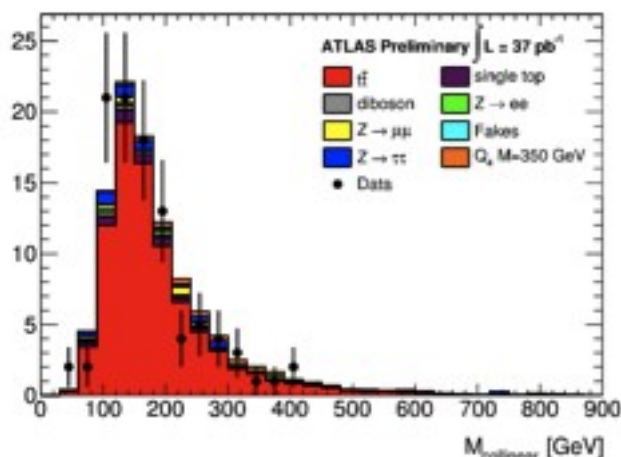
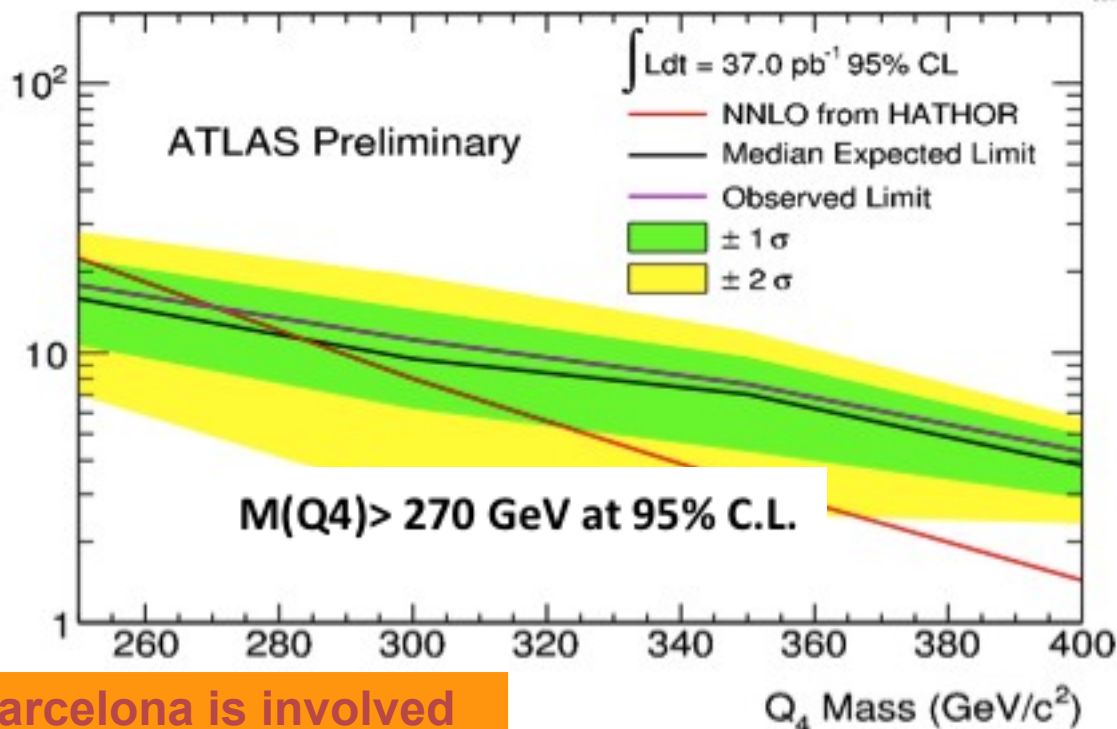


Lepton-neutrino collinear approximation (M_{coll})

Triangle cut on H_T and M_{coll}



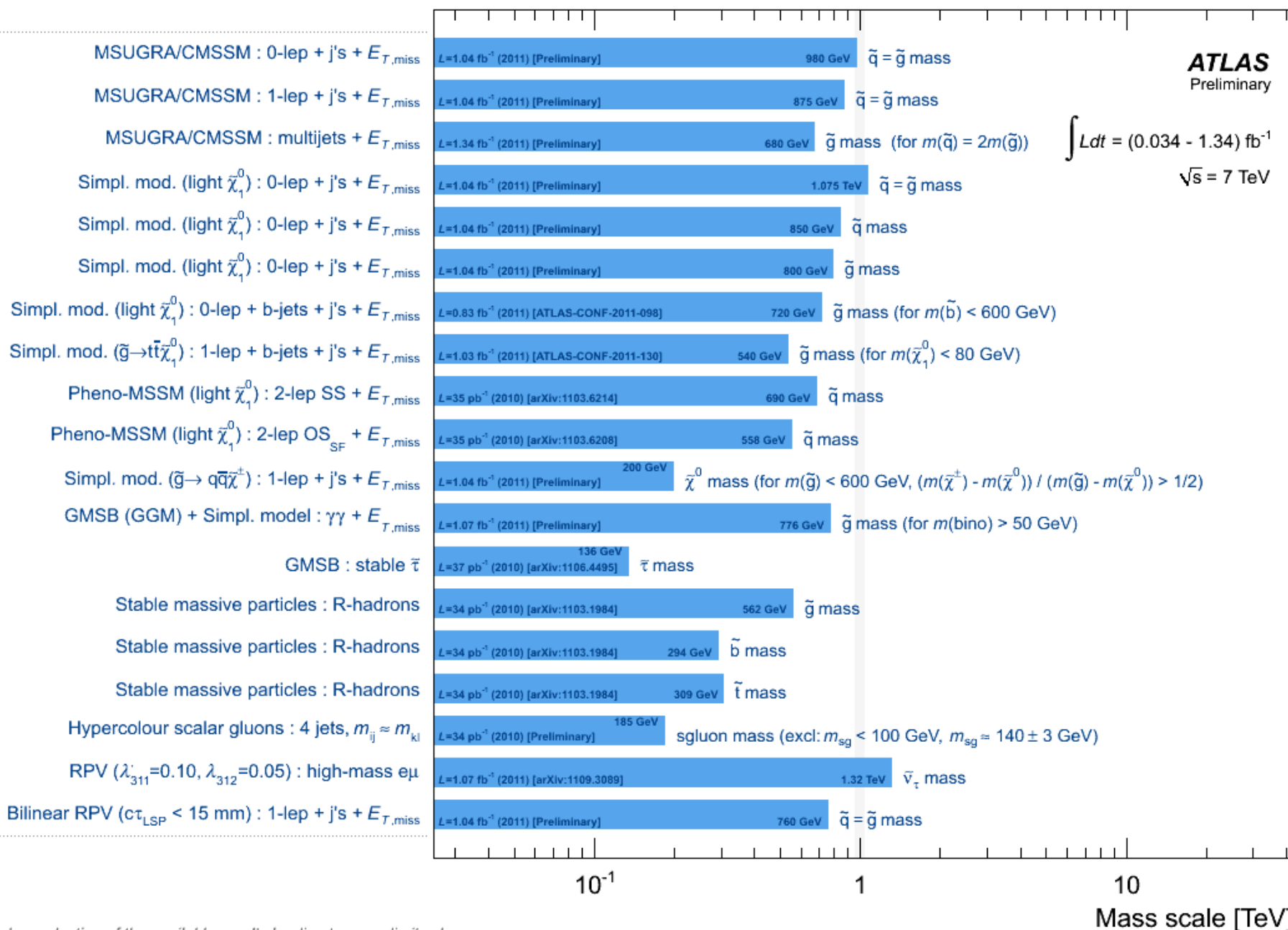
Cross Section (pb)





SUSY searches (summer 2011)

ATLAS SUSY Searches* - 95% CL Lower Limits (Status: BSM-LHC 2011)

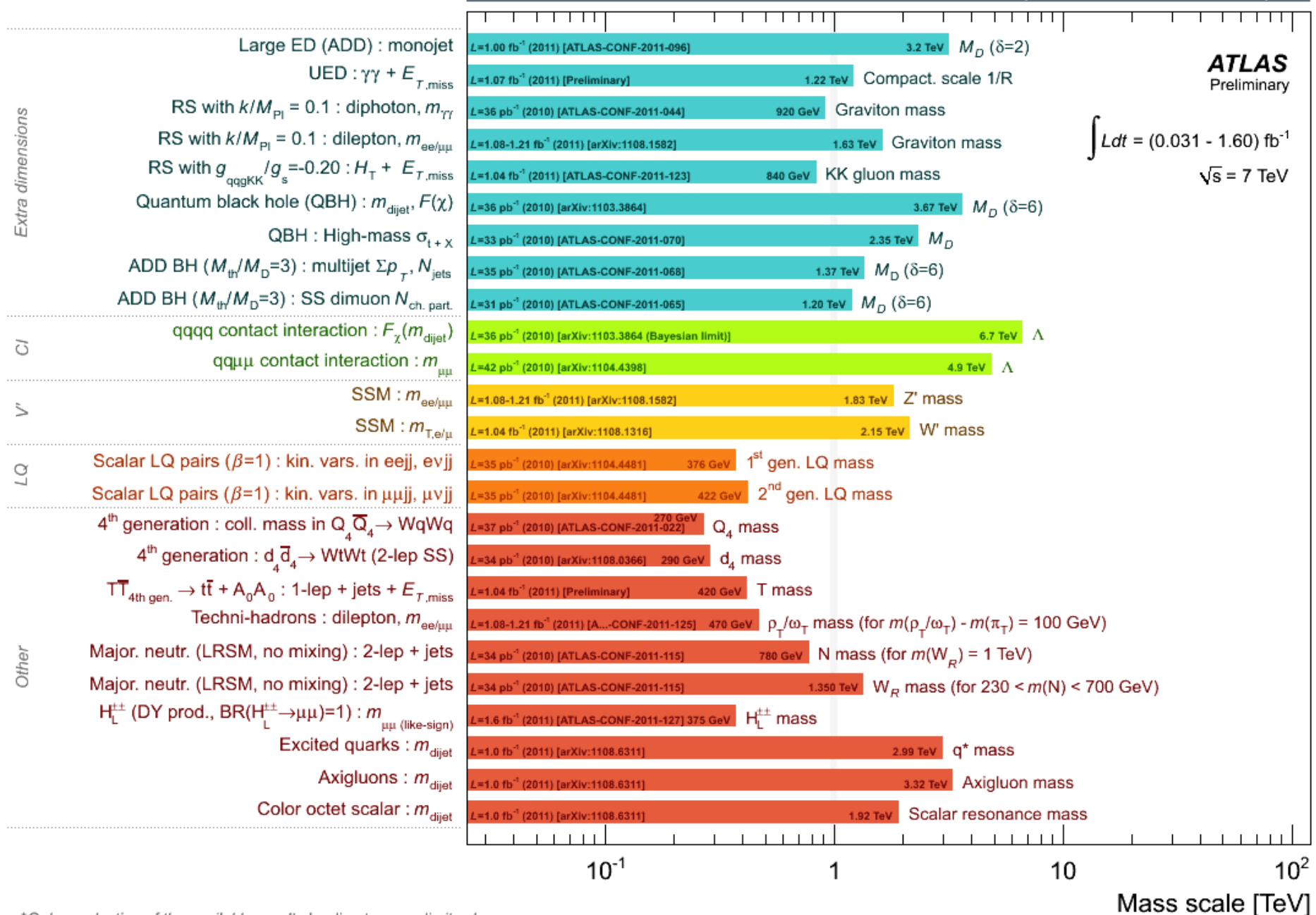


*Only a selection of the available results leading to mass limits shown



Exotics searches (summer 2011)

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: BSM-LHC 2011)



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

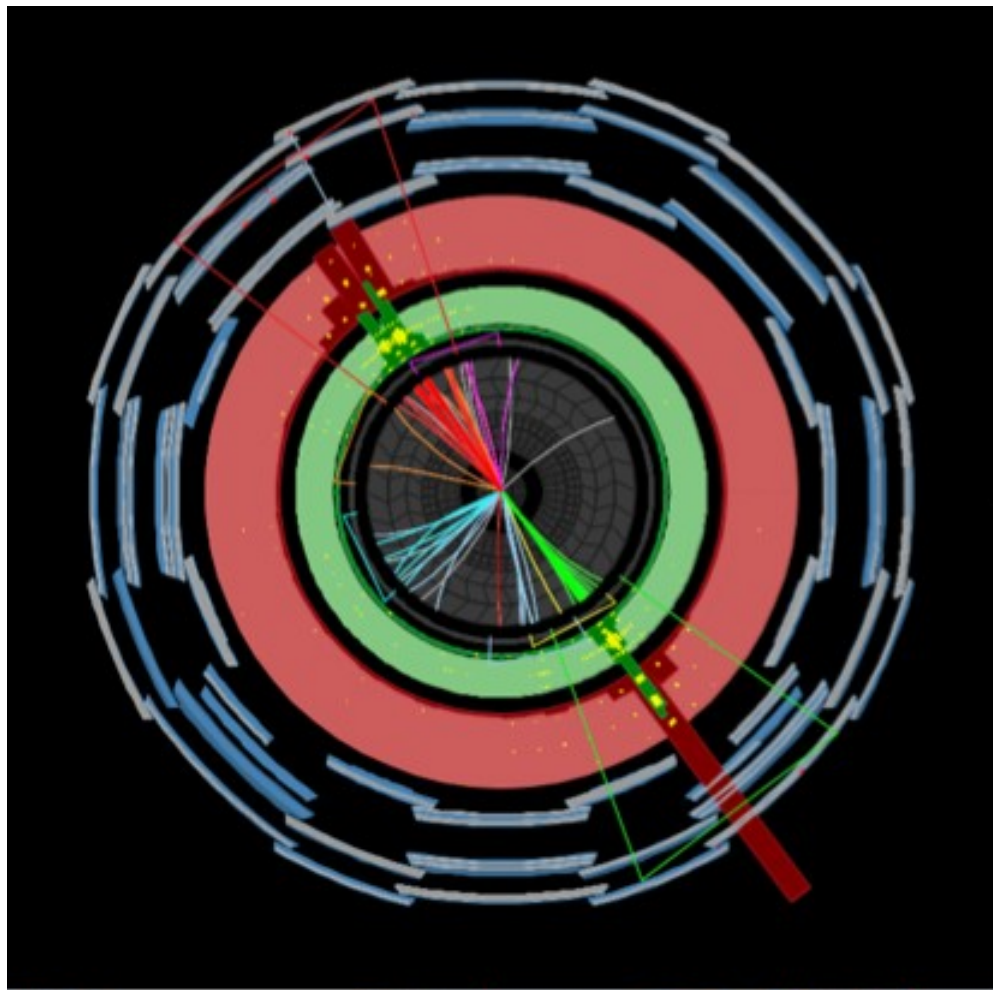


Summary

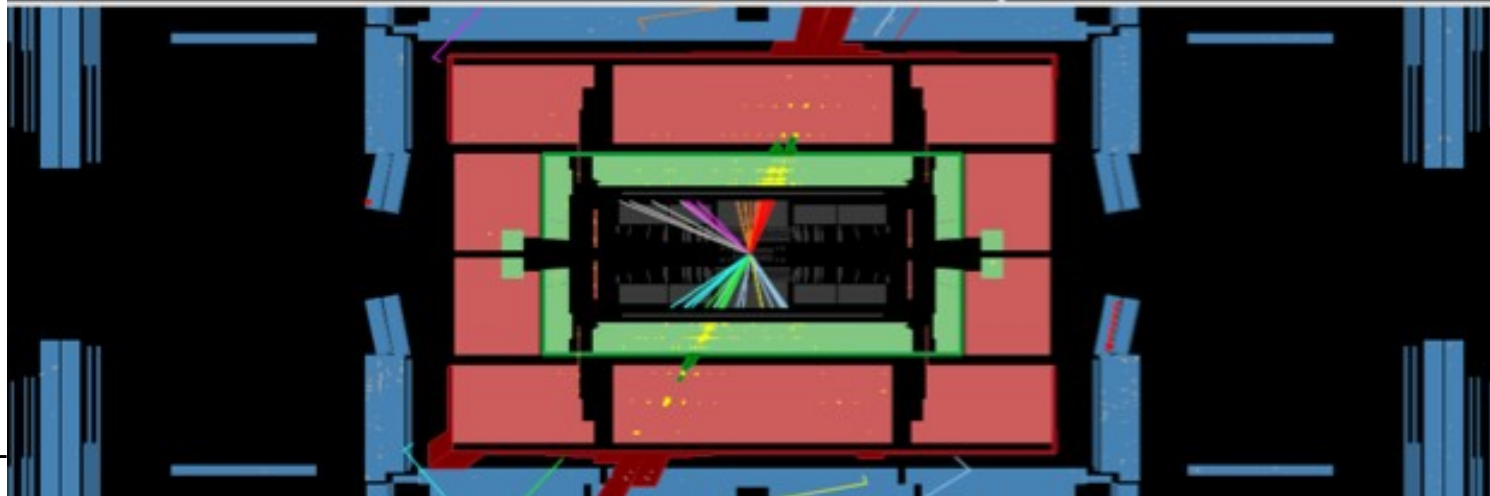
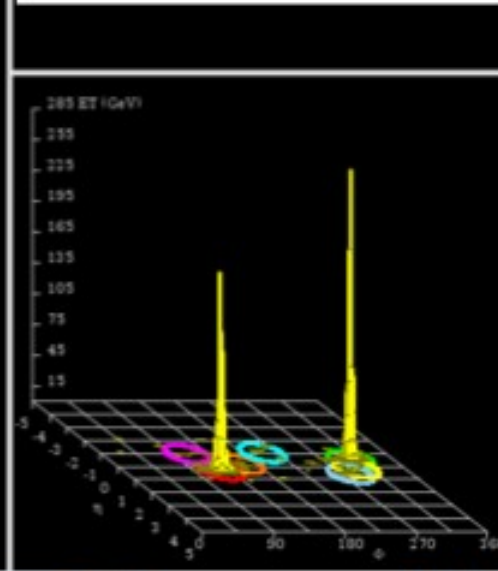
- Very good performance for the LHC and ATLAS, successful end of 2011 protons runs with $> 5 \text{ fb}^{-1}$.
- *Strong involvement of Spanish institutes (Valencia, Barcelona, Madrid) in physics analysis.*
- ATLAS SUSY and Exotics searches with $\sim 1 \text{ fb}^{-1}$ show no significant excess beyond Standard Model predictions.
- But still 5 fb^{-1} have to be analyzed...
- Looks like new physics is not just around the corner...
- Next year might bring more insights about physics BSM and Higgs searches.

Backup slides

Dijet final states



Very high energy jet event
 $m_{jj} = 4040 \text{ GeV}$
 $pt_{j1} = 1850 \text{ GeV}$
 $pt_{j2} = 1840 \text{ GeV}$
ATLAS-CONF-2011-081





Dijet final states: resonances

Physics Models:

Excited quarks q^*

Axigluons

Color-octet scalars

Observable

- Dijet invariant mass

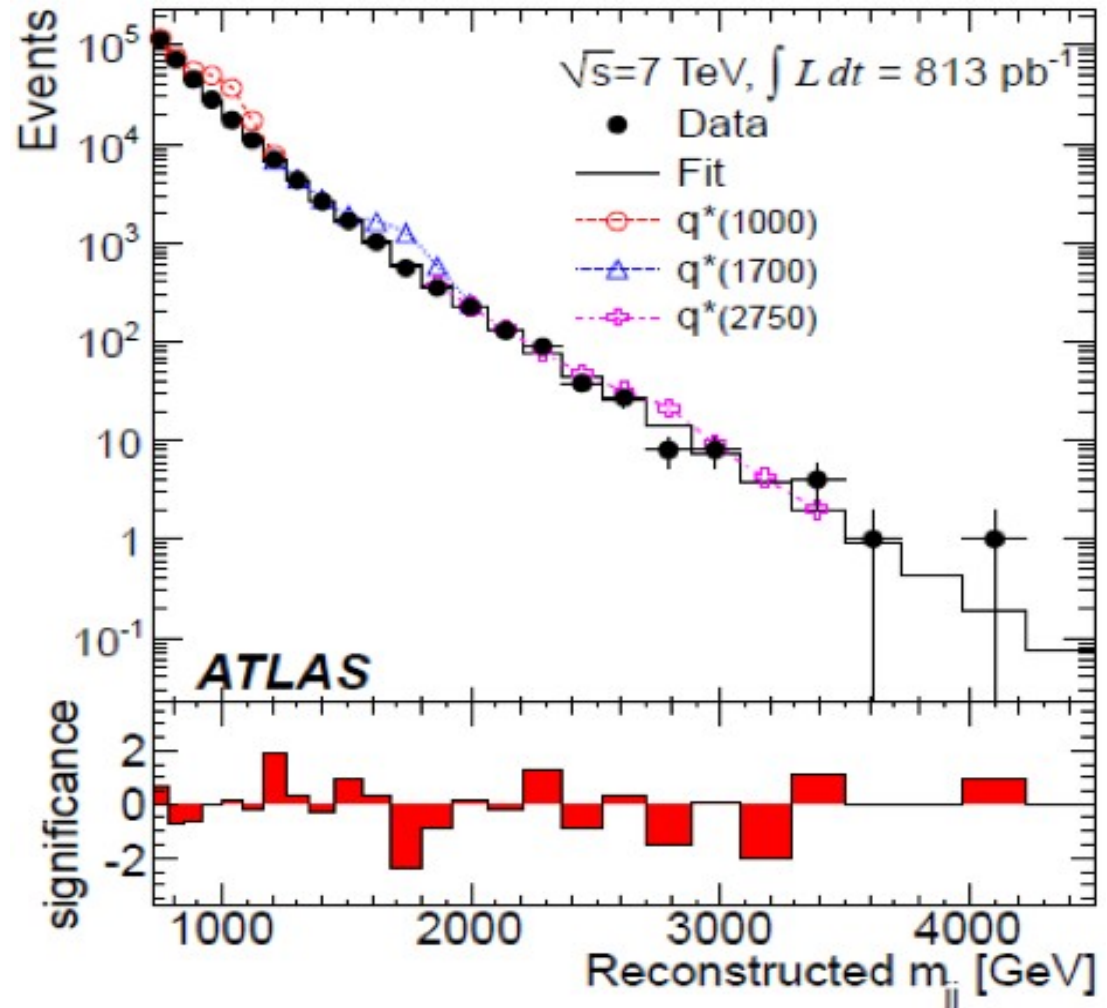
Events Selection

- Two highest pt jets with $|\eta| < 2.5$ and $|\Delta\eta_{jj}| < 1.3$

Background

- SM QCD parametrization

$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 \ln x}$$





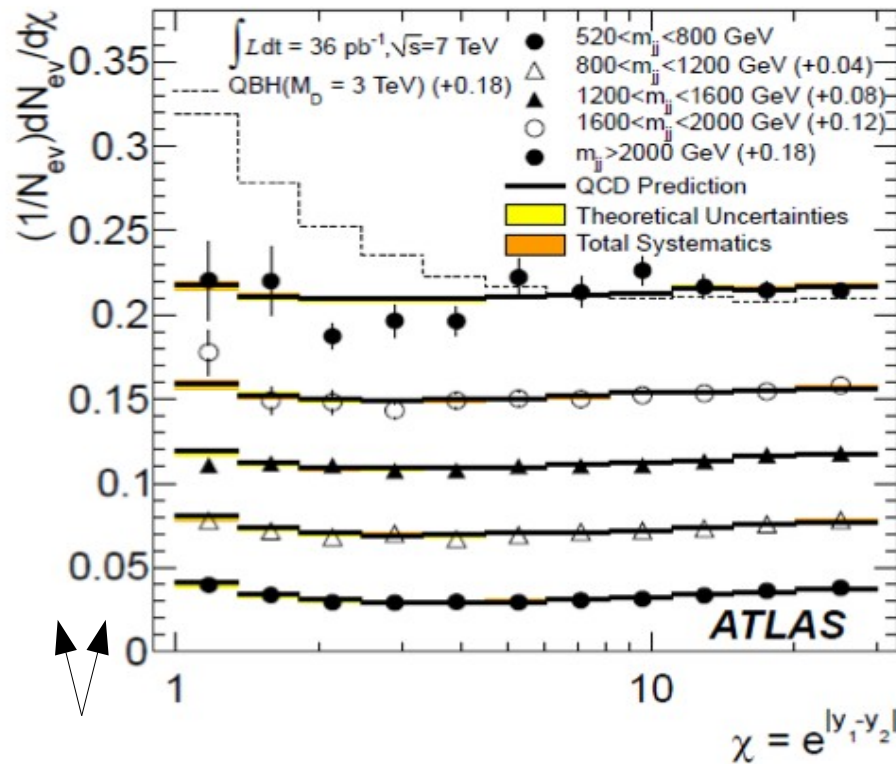
Dijet final states: angular distribution

Physics Model:

Quark contact interactions

Randall-Meade QBH

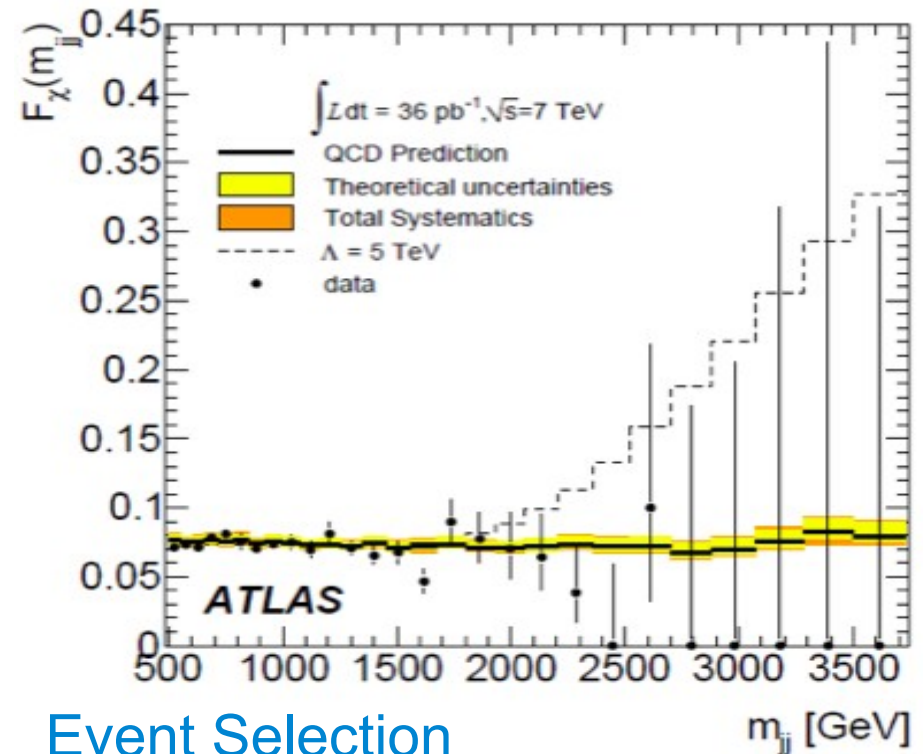
χ : Centrality in cm frame



➤ Observable

➤ Dijets angular distribution

F_χ : Centrality ratio in cm frame



➤ Event Selection

- At least two jets with $pt_{j1} > 60$ GeV and $pt_{j2} > 30$ GeV

➤ Background

➤ SM QCD (NLO) prediction



Dijet final states: Limits

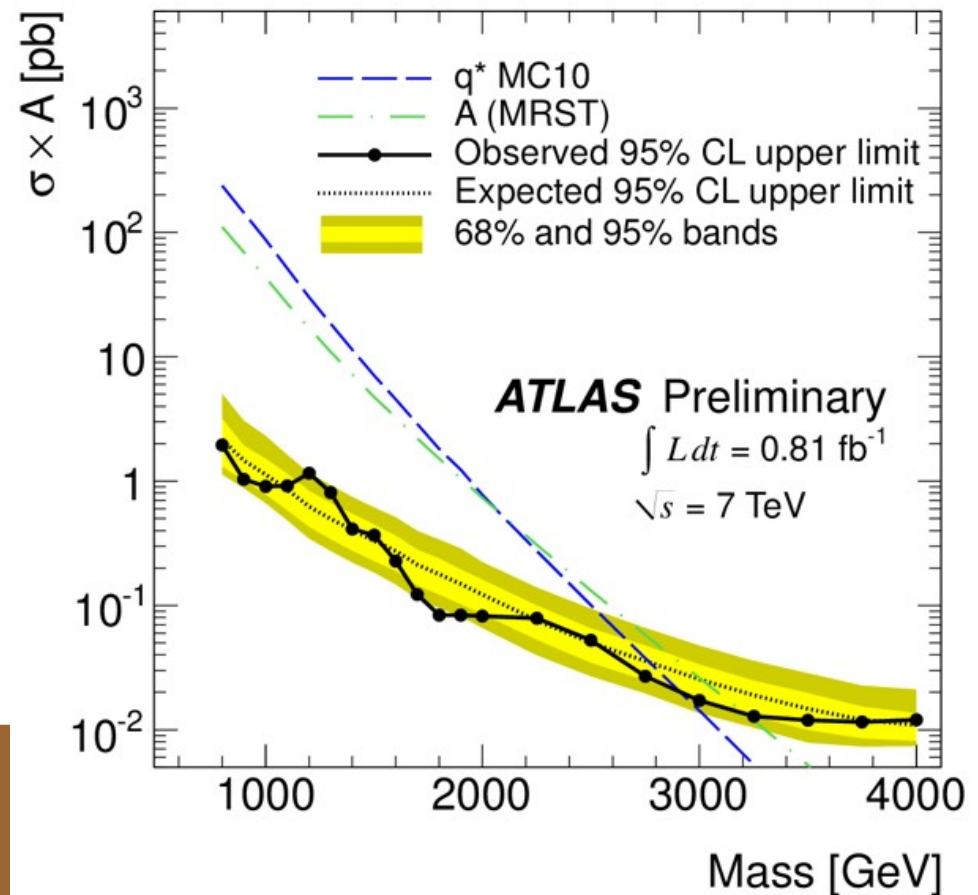
No evidence for new physics signal found

Observed (Expected) 95% C.L. Limits
(2011 data)

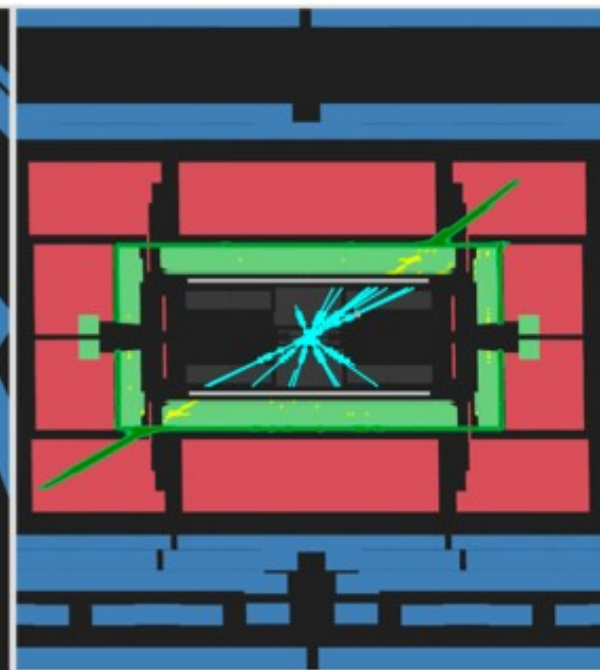
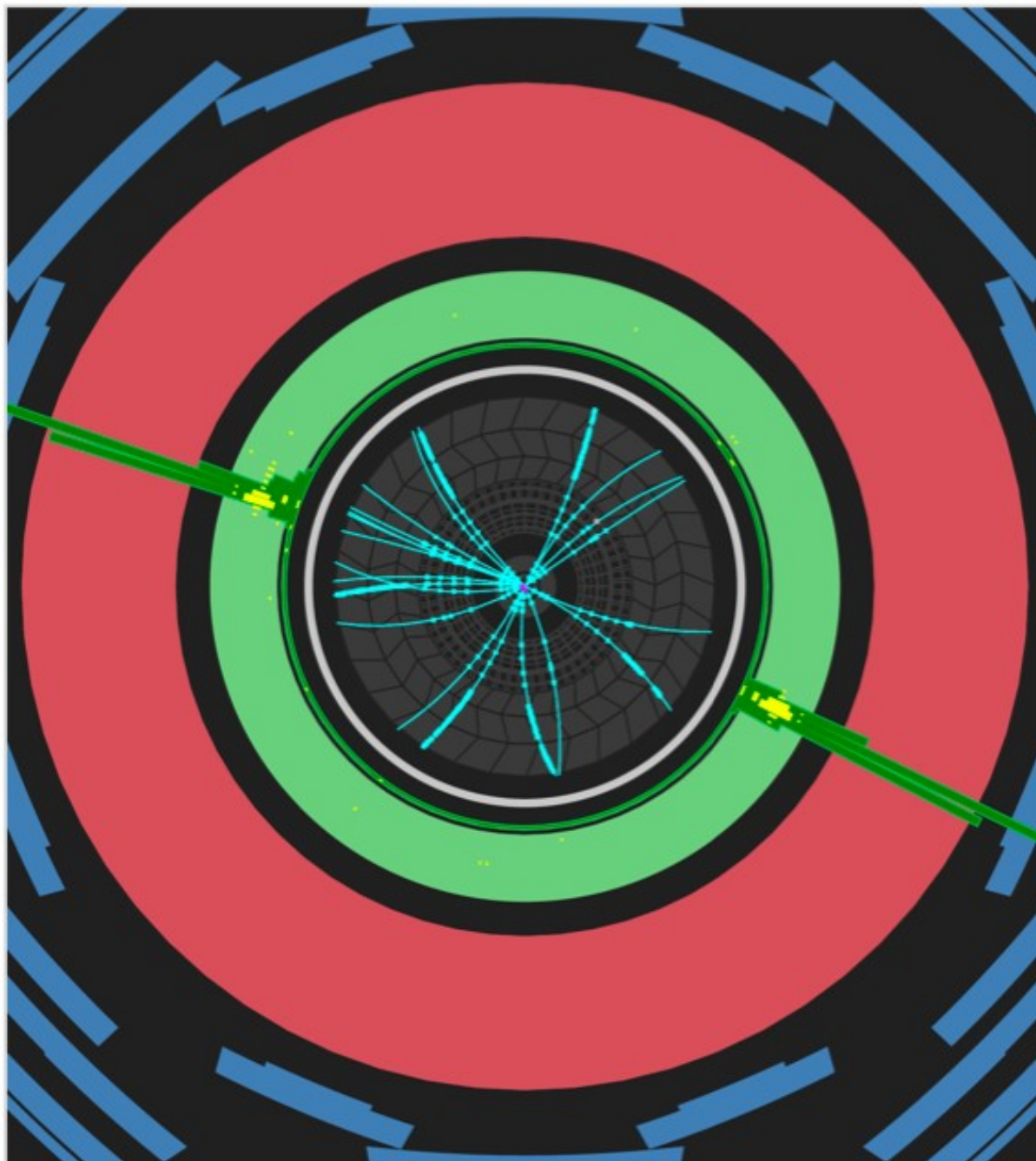
Excited quarks (q^*)	$M > 2.77$ (2.91) TeV
Axigluons	$M > 3.02$ (3.21) TeV
Color Octet Scalar	$M > 1.71$ (1.91) TeV

Observed (Expected) 95% C.L. Limits
(2010 data)

RMQ Black Hole ($n=6$)	$M > 3.67$ (3.64) TeV
Contact interaction	$\Lambda > 6.7$ (5.7) TeV



Diphoton final states



ATLAS
EXPERIMENT

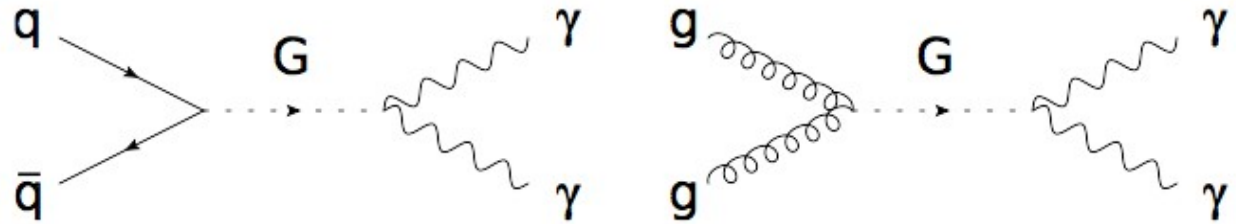
Run Number: 166786, Event Number: 77246540

Date: 2010-10-14 10:16:28 CEST

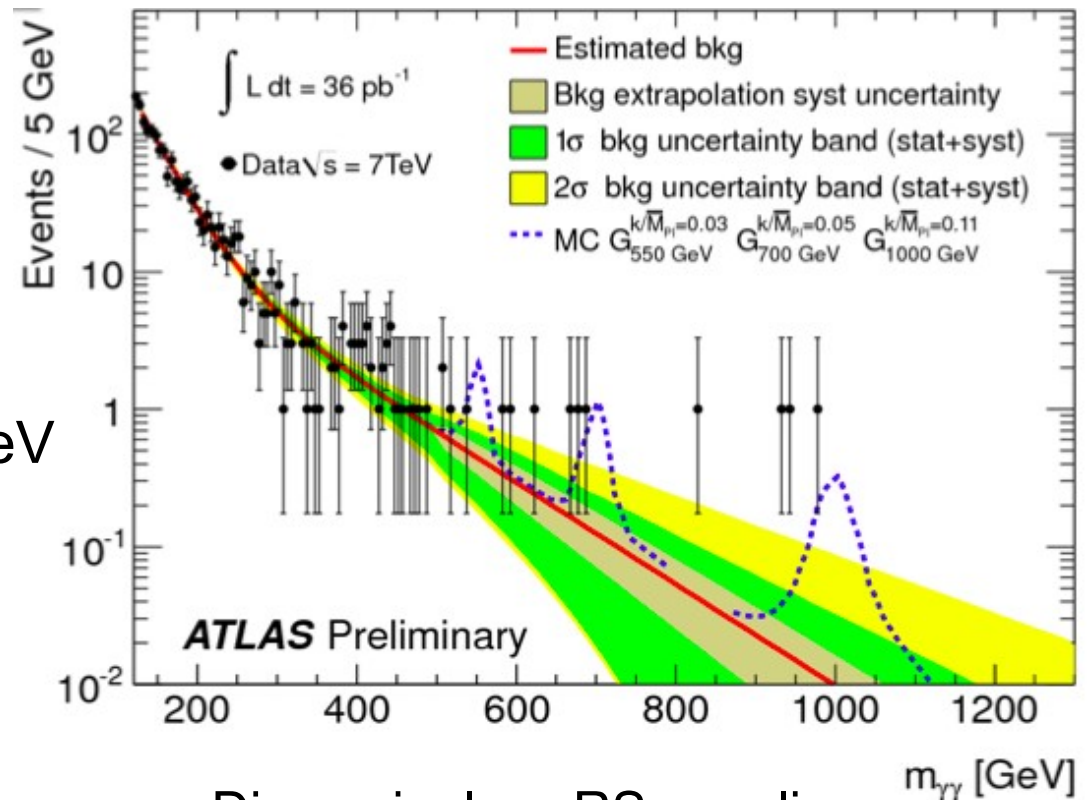


Diphoton final states

Physics Model:
Randall-Sundrum Graviton



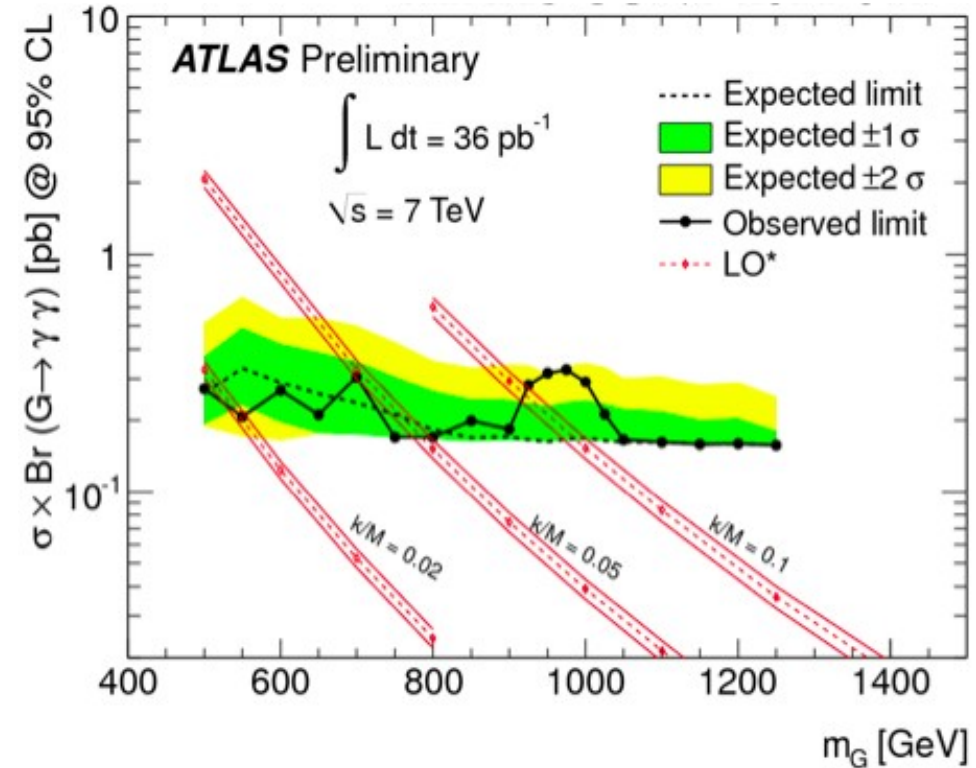
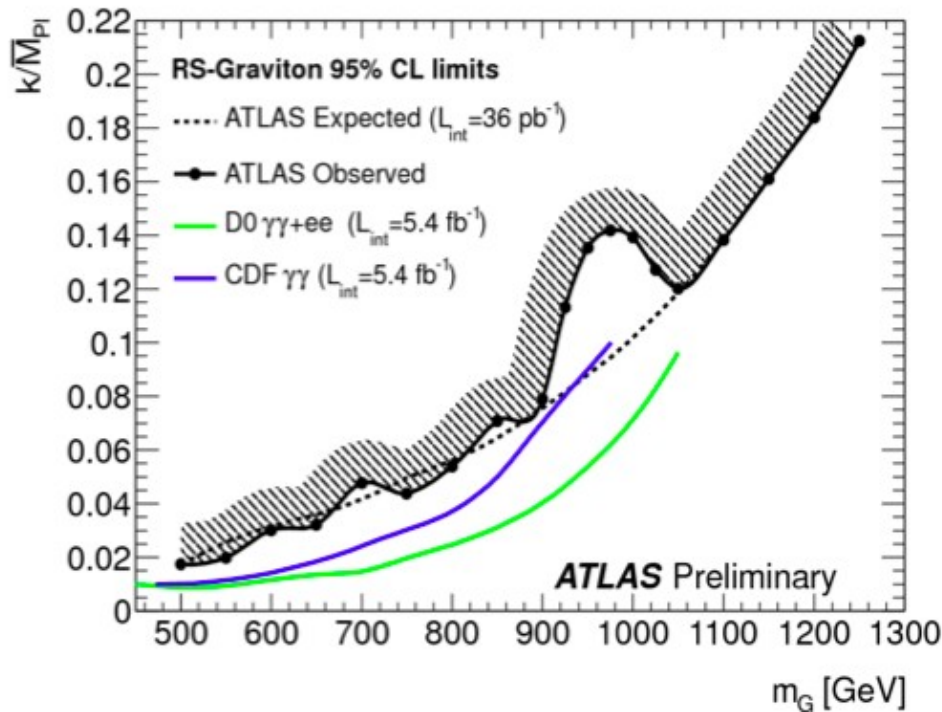
- **Observable**
 - Diphoton invariant mass
- **Selection**
 - Two photons with $p_T > 25$ GeV
- **Background**
 - SM diphoton production
 - fake photons from QCD



Dimensionless RS coupling
 k/M_{Pl} (from 0.02 to 0.1)



Diphoton final states



No evidence for new physics signal found
 Observed (Expected) 95% C.L. Limits (2010 data)
 $G \rightarrow \gamma\gamma$, $k/M=0.02$ $M > 545$ (503) GeV
 $G \rightarrow \gamma\gamma$, $k/M=0.1$ $M > 920$ (975) GeV



Diphoton with Large Missing Et

Physics Model:

GMSB with $\tilde{G}$ LSP ($\tilde{X}^0_1 \rightarrow \gamma \tilde{G}$)

UED ($\gamma^* \rightarrow \gamma + G$)

Observable

- Diphoton invariant mass

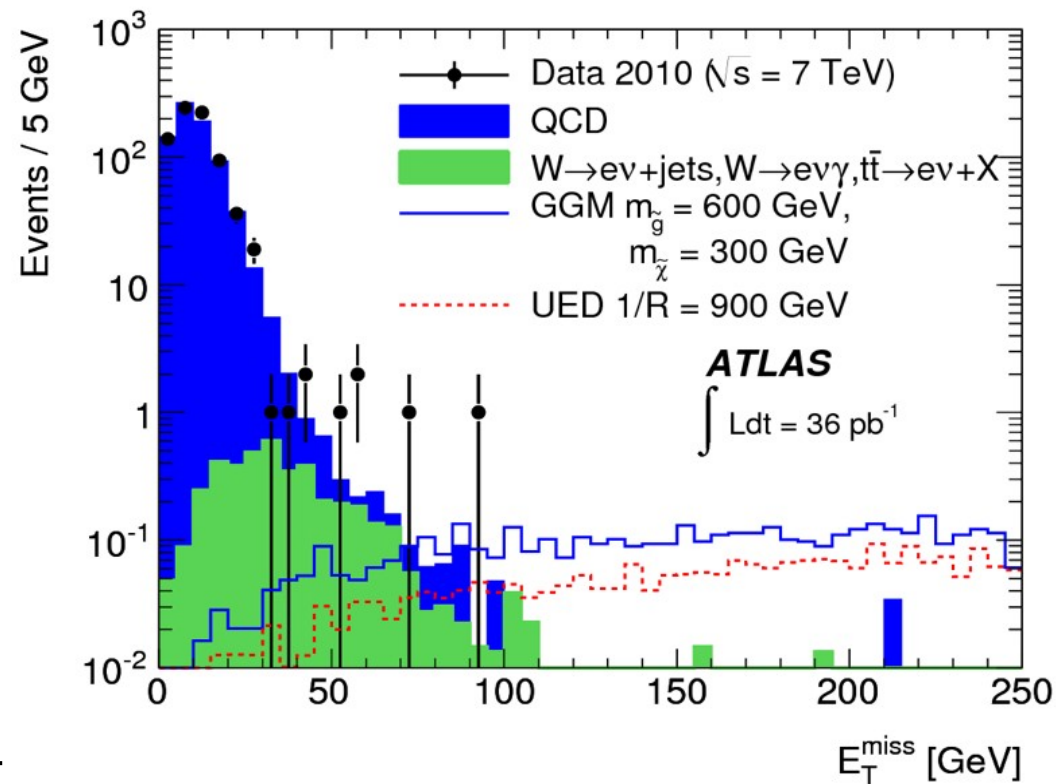
Event Selection

- Two photons, $E_T > 30(20)$ GeV
- missing $E_T > 125$ GeV

Background

- fake photons from QCD, γ +jet
- W+X and ttbar (electron and jet faking photons)

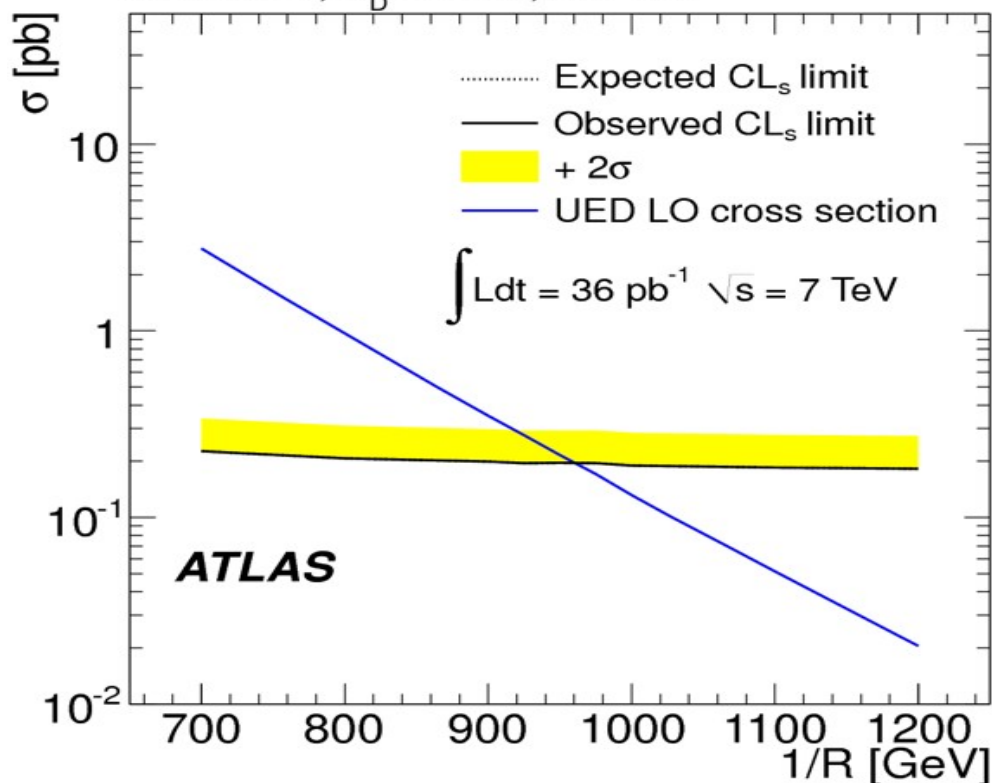
- **No candidate events survive the selection**



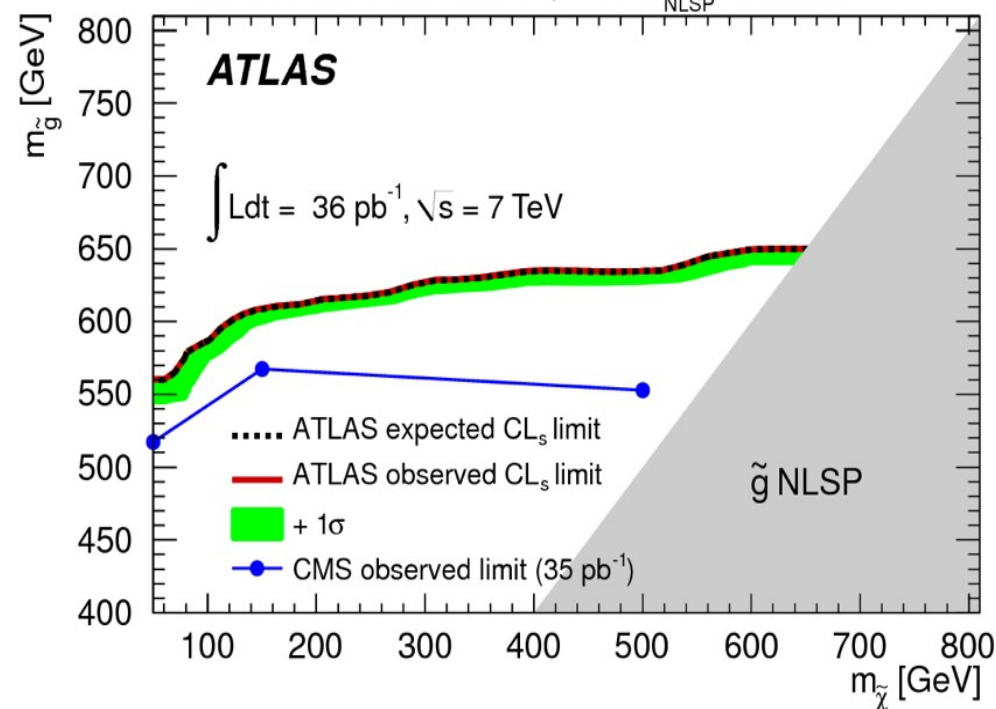


Diphoton plus large missing Et

UED: $N = 6$, $M_D = 5$ TeV, $\Delta R = 20$



GGM: bino-like neutralino, $\tan\beta = 2$, $c\tau_{\text{NLSP}} < 0.1 \text{ mm}$

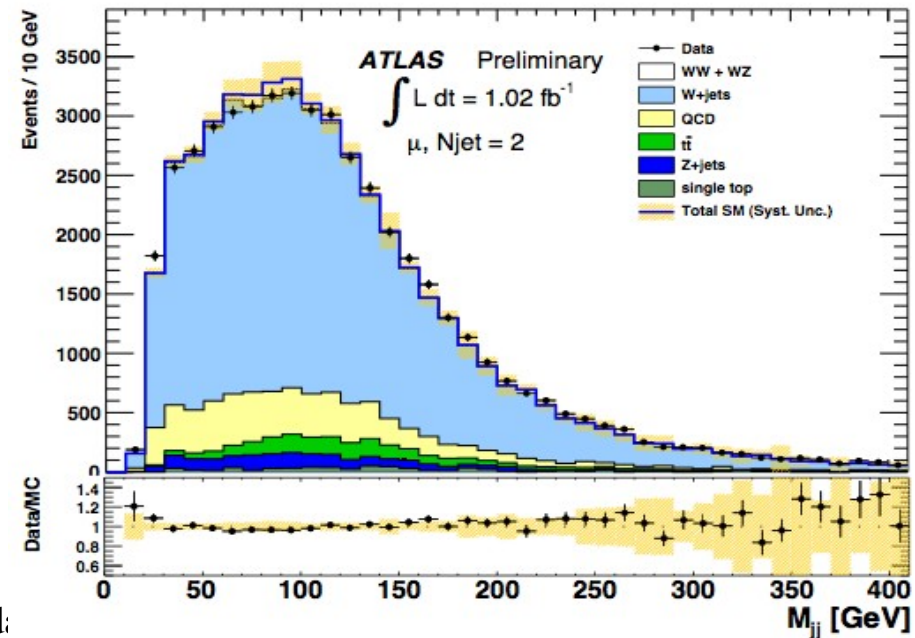
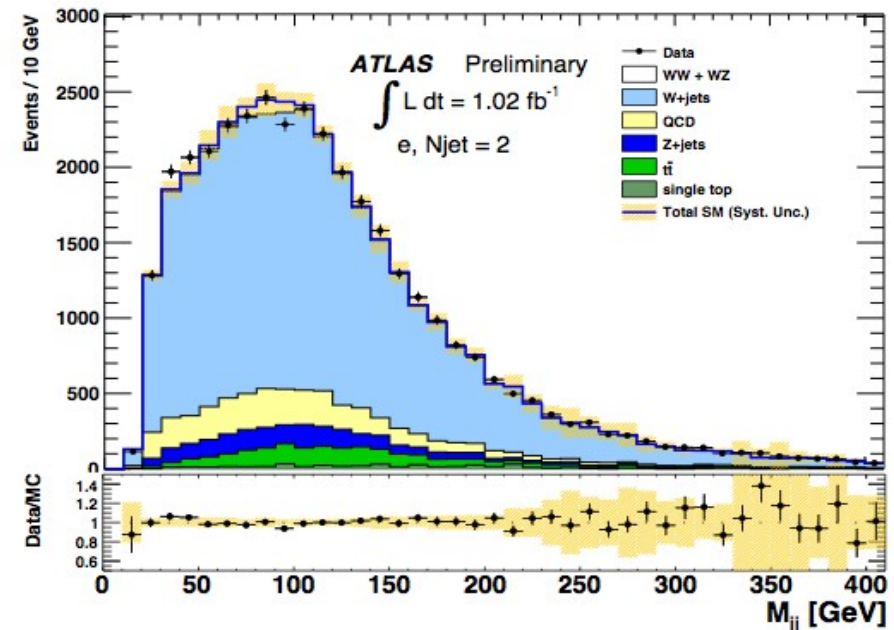


No evidence for new physics signal found
Observed (Expected) 95% C.L. Limits (2010 data)
UED: $1/R > 961$ (961) GeV
GMSB gluino: $M > 560$ (560) GeV



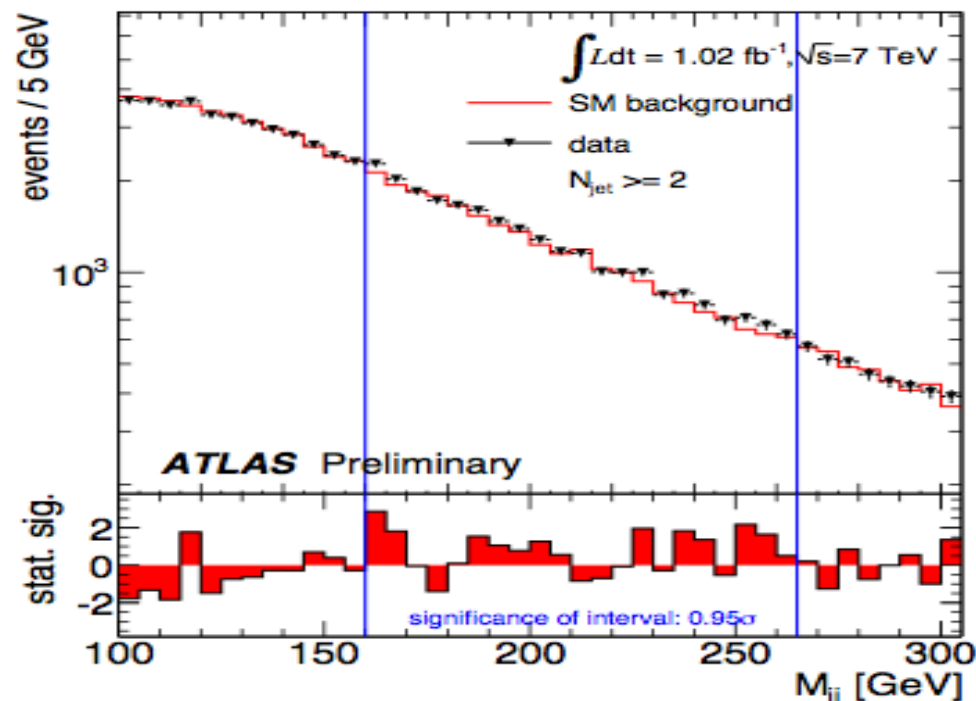
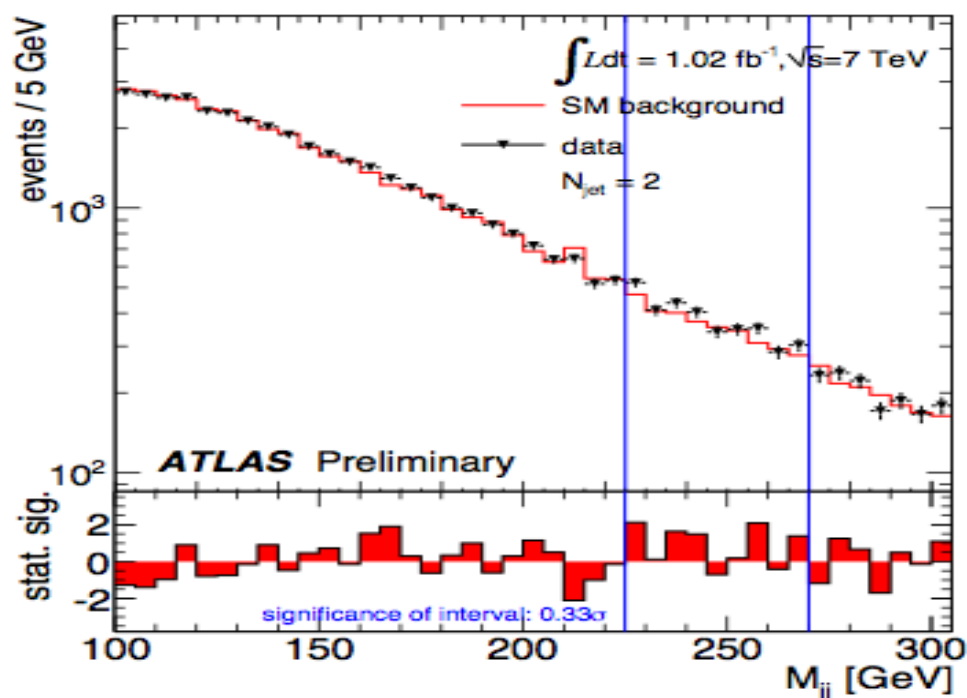
Dijet+lepton+MET final states

- **Observable**
 - Dijet invariant mass
- **Event Selection**
 - Two jets with one lepton (e, μ) and MET
- **Main backgrounds**
 - EW background (W+jets)
 - Diboson (WW, WZ)





Dijet+lepton+MET final states



No significant excess beyond the SM expectation is observed