Latest results on SUSY search from ATLAS

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LHC Physics Discussion
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Outline

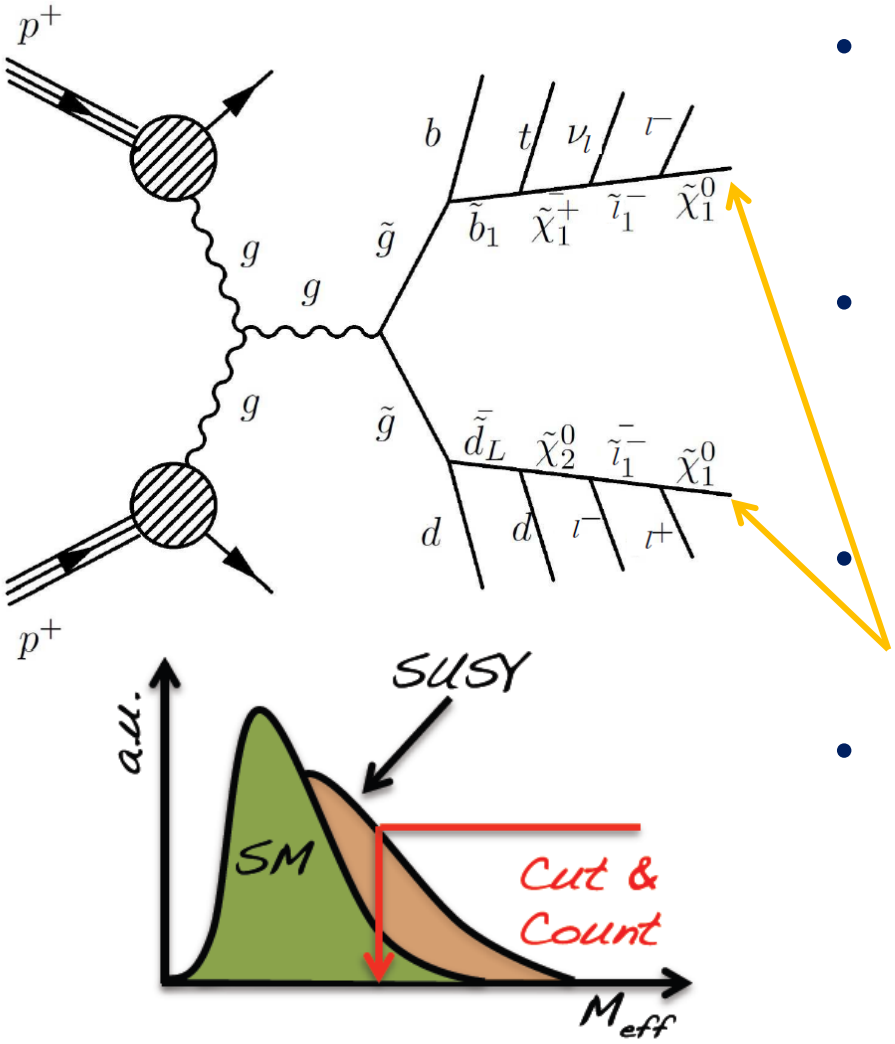
- Introduction to supersymmetry
- SUSY searches in ATLAS
  - 0-lepton + missing transverse energy (w/wo b-tag)
  - 1-lepton/2-lepton + missing transverse energy
  - 2 photon + missing transverse energy
- Searches for R-parity violating SUSY
  - Medium-lived particles with displaced vertex
  - eμ resonance
- Conclusion

Supersymmetry

- Unanswered questions in Standard Model (SM)
  - Why 3 generations?
  - Matter-antimatter asymmetry
  - What determines the masses and mixing parameters of SM?
  - What is dark matter?
- Supersymmetry (SUSY) as an extension of the Standard Model (SM)
  - SUSY provides an elegant solution to the hierarchy problem by introducing a super-partner to every SM particle (fermion – boson)
  - Provides a dark matter candidate
  - Unification of gauge couplings
- If SUSY is accessible, new particles are expected to be produced copiously at the LHC
  - Production of gluinos and squarks and their decays

Searches for SUSY at the LHC

Characteristic SUSY production and decay

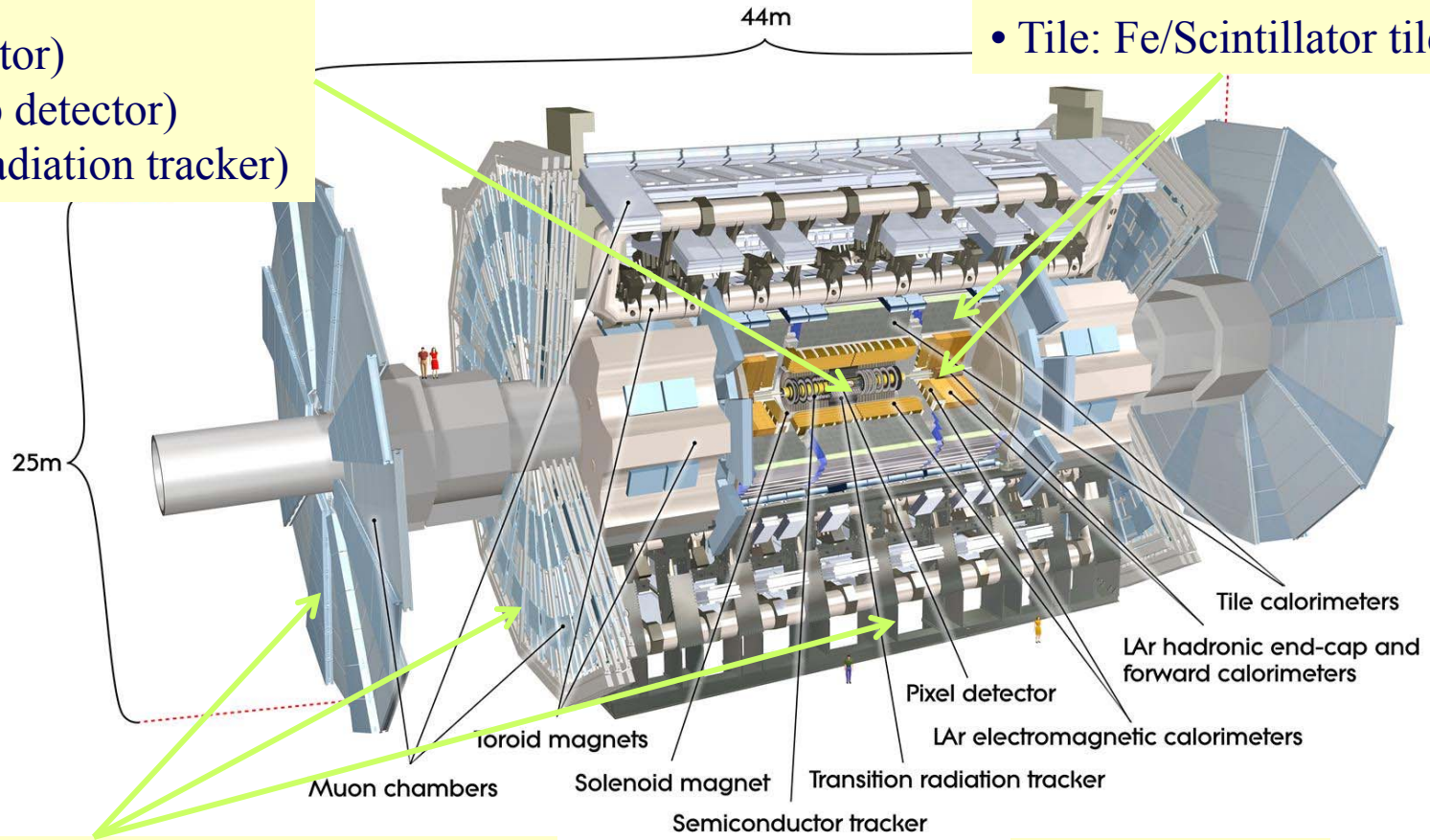


- In R-parity is conserved, SUSY particles are produced in pairs and the lightest SUSY particle (LSP) becomes stable
  - $R=(-1)^{3(B-L)+2s}$
- No direct observation of SUSY particles, but only SM particles are reconstructed directly
  - No mass peaks
- LSP escapes the detector undetected producing a missing transverse energy (E_T^{miss})
- Evidence of SUSY is done by establishing an excess of events in some region of phase space
  - Crucial to understand the contribution from SM processes

ATLAS experiment

Inner Detector
- Pixel (pixel detector)
- SCT (silicon strip detector)
- TRT (transition radiation tracker)

Calorimeter
- LAr : EM calorimeter
- Tile: Fe/Scintillator tile



Muon spectrometer
- MDT, CSC : precise momentum measurement
- RPC, TGC : trigger chambers

Magnet system
- 2 T solenoid
- 0.5 T toroid

Overview of SUSY searches in ATLAS

Channel	Signature	Integrated lumi.
0-leptons+jets+E_T^{miss}	≥2-4 jets, large E_T^{miss}, m_{eff}	1.04 fb^{-1}
1-leptons+jets+E_T^{miss}	≥3 jets, e or μ, large E_T^{miss}, m_{eff}	165 pb^{-1}
2-leptons+E_T^{miss}	Exactly 2 leptons, large E_T^{miss}	35 pb^{-1}
0-leptons+bjets+E_T^{miss}	≥3 jets, large E_T^{miss}, m_{eff}	0.83 fb^{-1}
Diphoton+E_T^{miss}	γγ+E_T^{miss}+X	36 pb^{-1}
eμ resonance	eμ+X	0.87 fb^{-1}
Medium-lived particle	μ+displaced vertex	35 pb^{-1}

- Interpretation of search results in the context of
  - mSUGRA/CMSSM model
    - M_0, $M_{1/2}$, A_0, tanβ, sgn(μ)
  - Simplified model

$$m_{eff} = \sum_{i=1}^{n} \left| p_T^i \right| + E_T^{miss}$$

E_T^{miss} + jets + 0-lepton channel

NEW L=1.04 fb^{-1}

Five signal regions are defined to maximize sensitivities for various production mechanisms

$$\tilde{q}\tilde{q} \rightarrow (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$$
$$\tilde{g}\tilde{q} \rightarrow (qq\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$$
$$\tilde{g}\tilde{g} \rightarrow (qq\tilde{\chi}_1^0)(qq\tilde{\chi}_1^0)$$

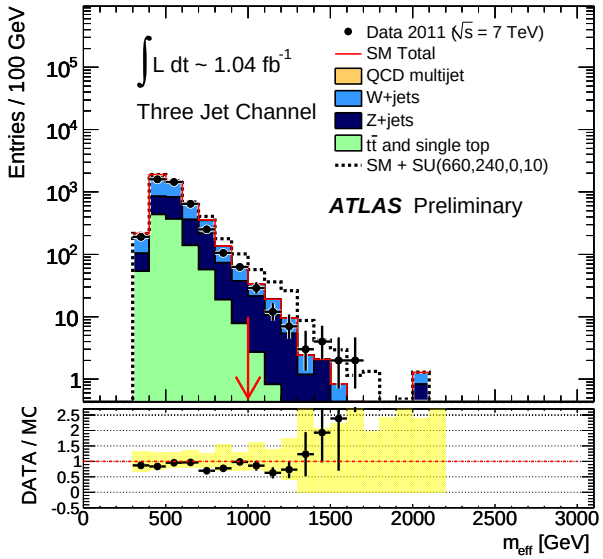
Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}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

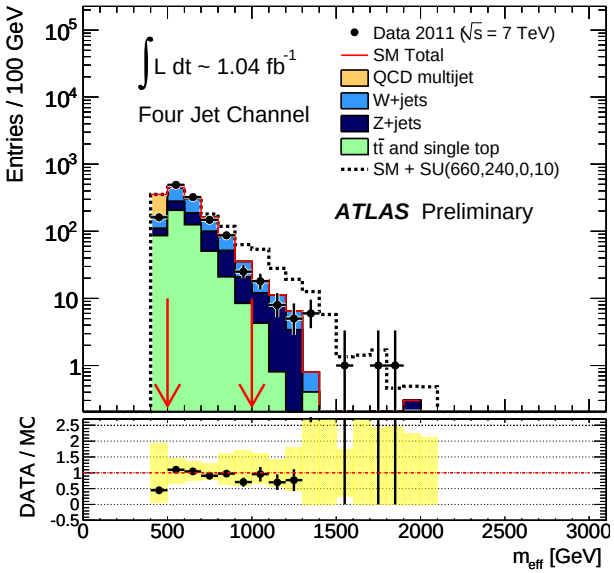
Background sources	
W+jets	Leptons reconstructed as jets
Z/γ+jets	γ/leptons as jets, Z+jets→νν+jets
Top	Hadronic tau decay
QCD	Mis-measurement of jets or ν from heavy flavor decay

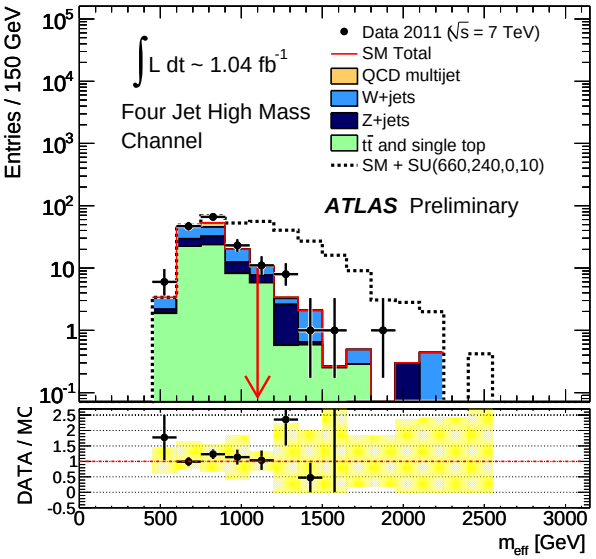
All backgroud estimations are data-driven

Search in 0-lepton : Results

NEW L=1.04 fb^{-1}







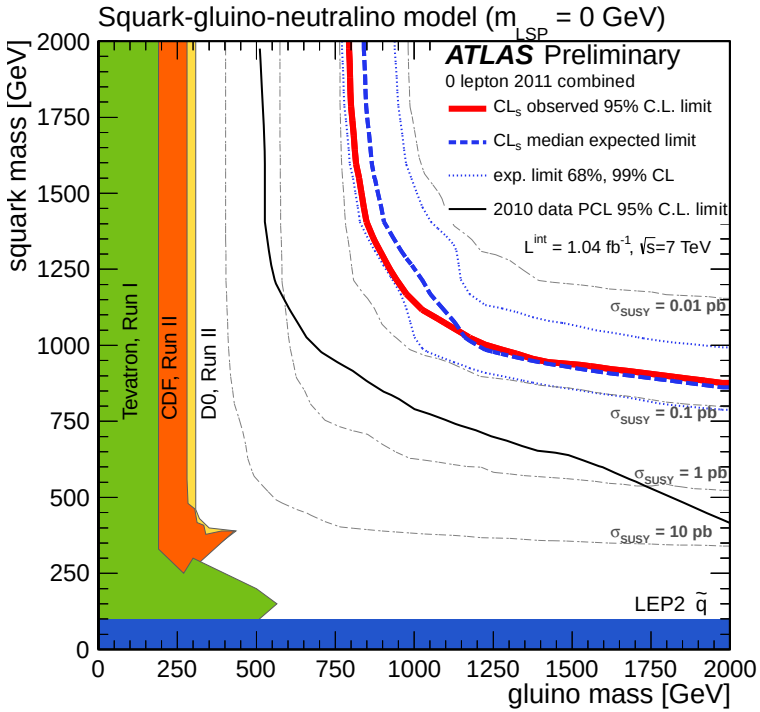
	≥2 jets	≥3 jets	≥4 jets m$_{eff}$>500 GeV	≥4 jets m$_{eff}$>1000 GeV	≥4 jets high mass
Total expected	62.3±4.3±9.2	55.0±3.8±7.3	984±39±145	33.4±2.9±6.3	13.2±1.9±2.6
Data	58	59	1118	40	18
Limit on fiducial cross section	22 (fb)	25 (fb)	429 (fb)	27 (fb)	17 (fb)

No excess was observed

E_T^{miss} + jets + 0-lepton : Interpretation

Phenomenological MSSM (squark-gluino) grids

- Masses from 100 GeV to 2 TeV, $m(\chi^0_1)=0$
- Limits unchanged if LSP mass raised to 200 GeV

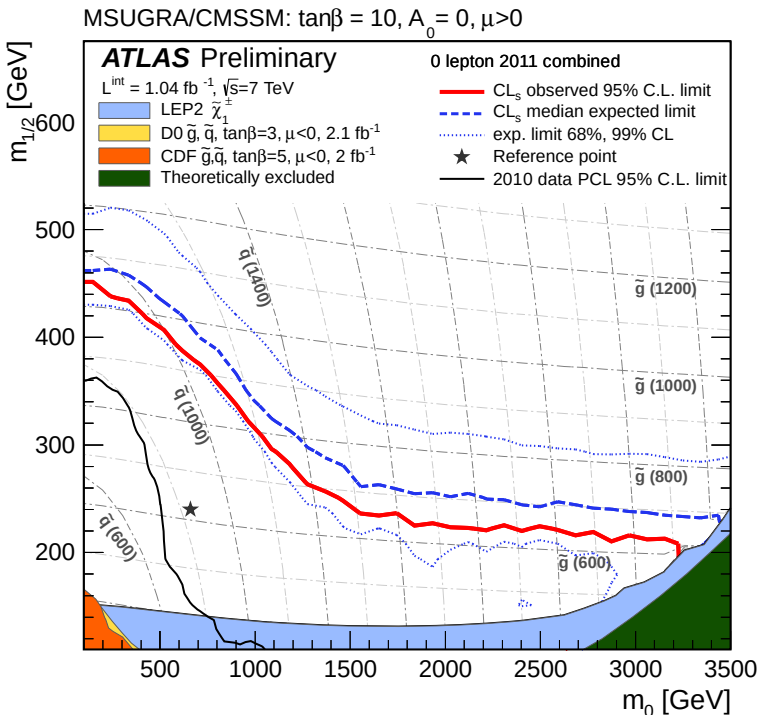


Exclude at 95 % C.L.

$m_{\tilde{g}} < 800$ GeV, $m_{\tilde{q}} < 850$ GeV

if $m_{\tilde{g}} = m_{\tilde{q}}$, masses <1075 GeV

mSUGRA/CMSSM, A0=0, tanβ=10, μ>0



Exclude at 95 % C.L.

if $m_{\tilde{g}} = m_{\tilde{q}}$, masses <980 GeV

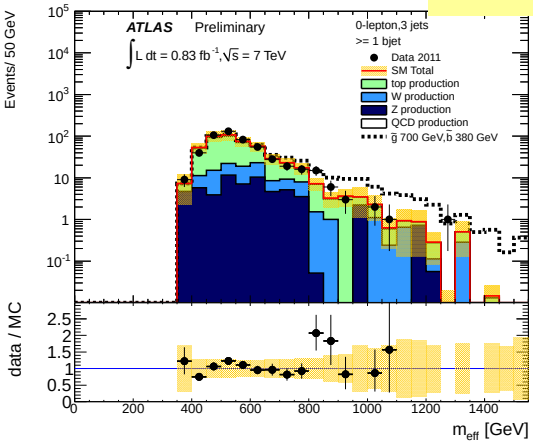
E_T^{miss} + bjets + 0-lepton

NEW L=0.83 fb^{-1}

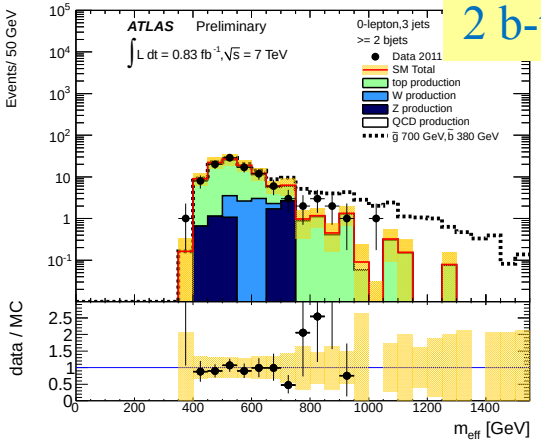
- Analysis similar to jets+ channel but requires at least one b-jet
- Sensitive to 3rd generation squarks in R-parity conserving scenarios
- Define 4 signal regions to maximize sensitivity

3J-A	3J-B	3J-C	3J-D
≥1 b-tag m_{eff}>500 GeV	≥1 b-tag m_{eff}>700 GeV	≥2 b-tag m_{eff}>500 GeV	≥2 b-tag m_{eff}>700 GeV

1 b-tag



2 b-tag



Pheonomenological MSSM

$$m_{\tilde{g}} > m_{\tilde{b}_1} > m_{\tilde{\chi}_1^0}$$

$$\tilde{g} \to \tilde{b}_1 b, \tilde{b}_1 \to b\tilde{\chi}_1^0 \ (100\,\%)$$

$$m_{\tilde{\chi}_1^0} = 60\ \text{GeV}$$

General simplified model

- Squarks assumed to be heavy
- Gluino-gluino pair production

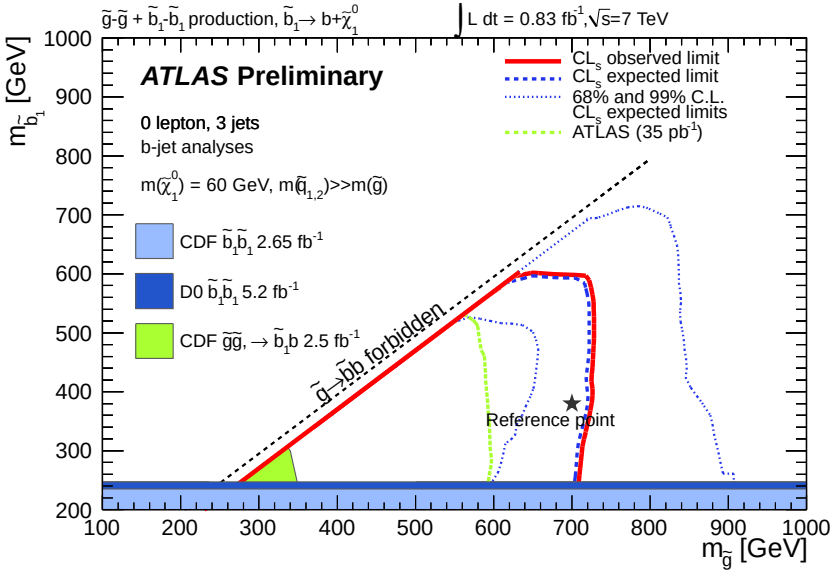
$$\tilde{g} \to bb\tilde{\chi}_1^0 \ (3\text{-body decay})$$

E_T^{miss} + bjets : Results

NEW L=0.83 fb^{-1}

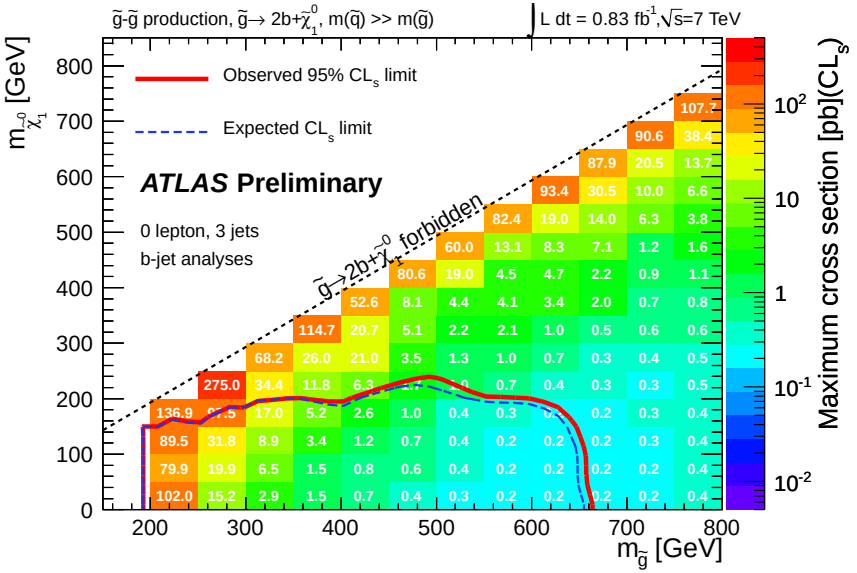
Signal region	3J-A	3J-B	3J-C	3J-D
Total expected	356^{+103}_{-92}	70^{+24}_{-22}	79^{+28}_{-25}	$13^{+5.6}_{-5.2}$
Data	361	63	76	12
σ (pb) 95 % C.L. upper limit	0.288	0.061	0.078	0.017

Phenomenological MSSM



Gluino masses below 720 GeV excluded for sbottom masses below 600 GeV

Simplified model (gluino→bbχ^0_1)



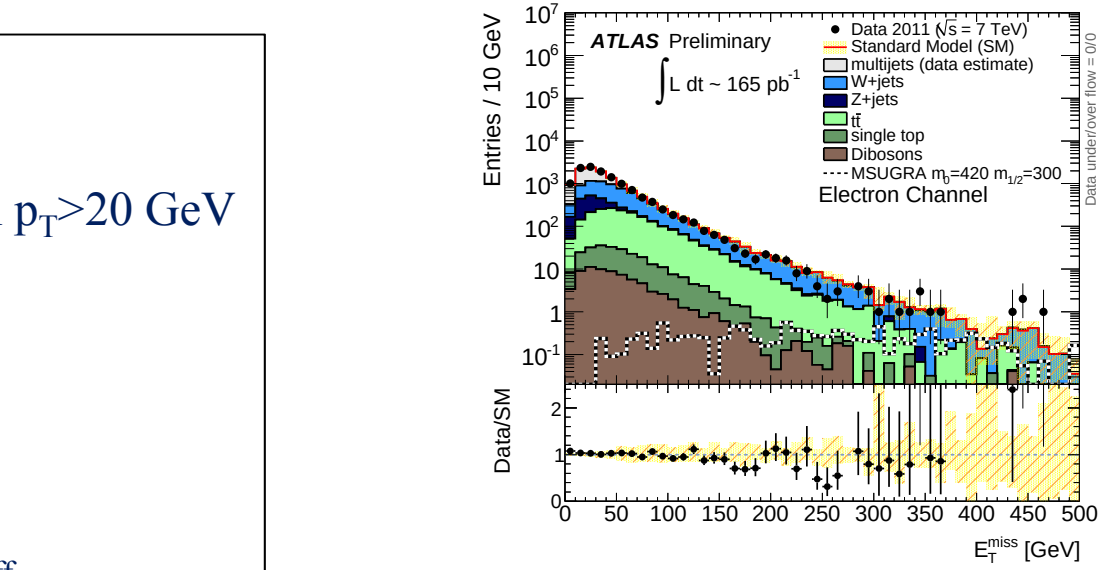
Gluino masses between 200-660 GeV excluded up to LSP mass of 160 GeV

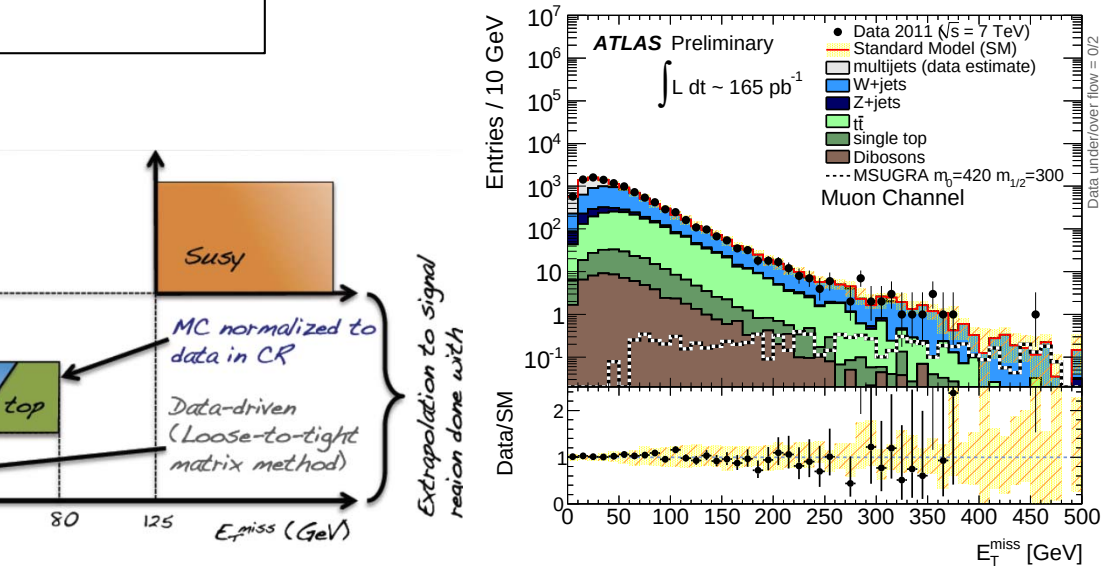
E_T^{miss} + jets + 1-lepton

NEW L=165 pb^{-1}

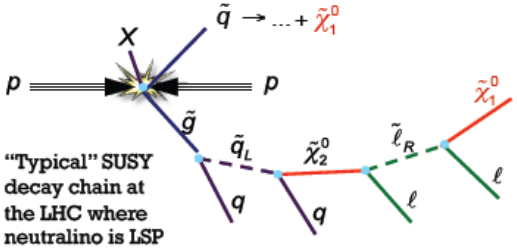
Event selection

- 1 lepton (electron or muon)
  - electron p_T>25 GeV or muon p_T>20 GeV
  - Veto second lepton if
    - electron p_T>20 GeV or
    - muon p_T>10 GeV
- 3 jets (>60, >25, >25 GeV)
- $\Delta\varphi$(jet, E_T^{miss})> 0.2 for all jets
- E_T^{miss} >125 GeV, E_T^{miss} >0.25*M_{eff}
- M_{eff}>500 GeV



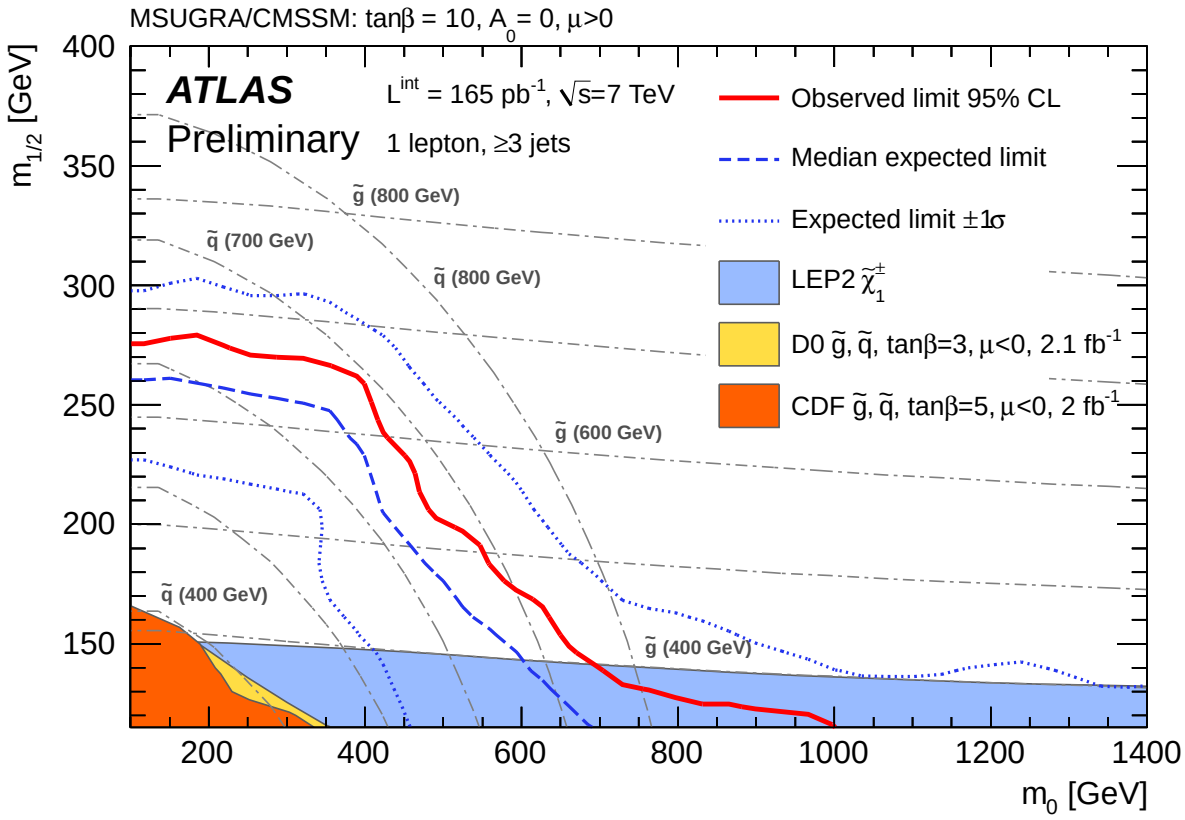


Main background: W+jets



E_T^{miss} + 1-lepton : Interpretation

- No excess observed
- Limit in the context of mSUGRA/CMSSM



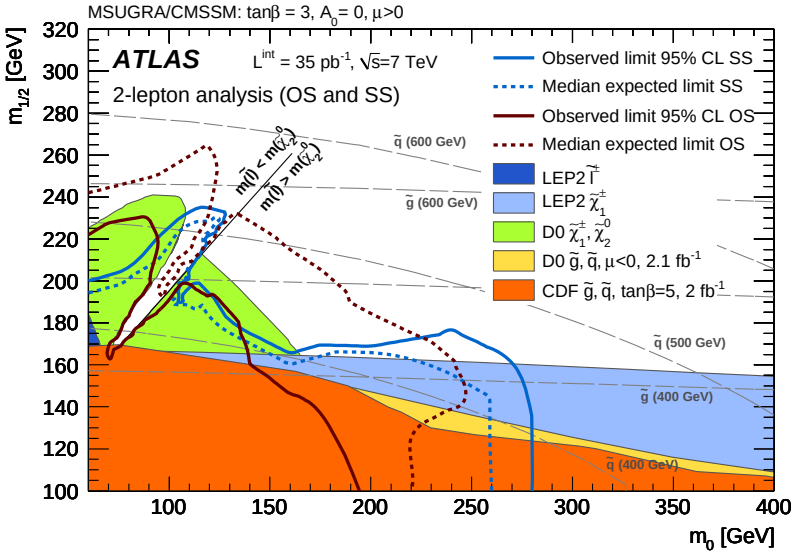
	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$ [fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	$p(s=0)$
Electron channel	41	6.8	$10.6^{+6.6}_{-4.7}$	0.24	0.77
Muon channel	53	8.8	$8.8^{+5.7}_{-3.8}$	0.50	0.51

E_T^{miss} + 2-lepton

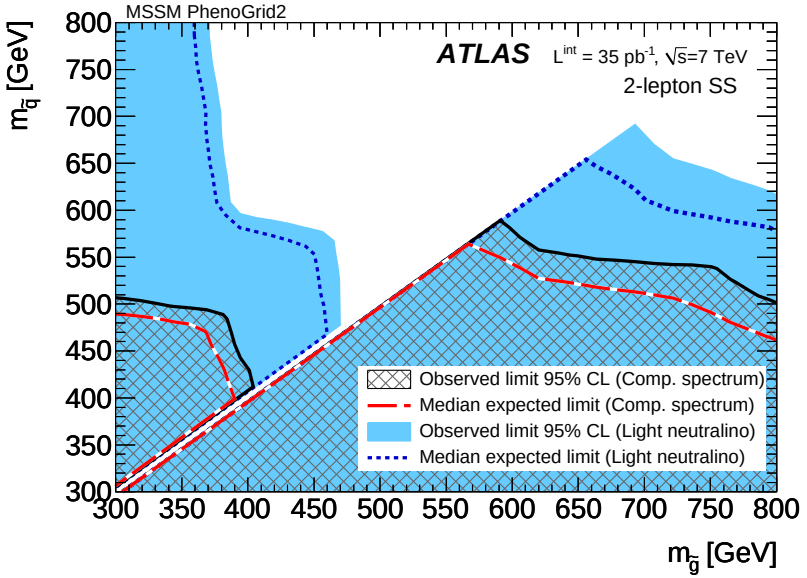
L=35 pb^{-1}

- Exactly 2 leptons
  - Opposite-sign (OS)/Same-sign (SS)
- E_T^{miss} >100 (for SS), 150 GeV (for OS)

- mSUGRA/CMSSM, A0=0, tanβ=3, μ>0
  - m(gluino,squark)>450-690 GeV



- Phenomenological MSSM (2 grids)
  - "Compressed spectrum"
    - → soft final state kinematics
  - Light neutralino
    - → harder kinematics



Limits on model independent fiducial cross sections @95 % C.L.

e^+e^-	$\mu^+\mu^-$	$e^+\mu^-$	ll (SS)
0.09 pb	0.21 pb	0.22 pb	0.07 pb

Diphoton + E_T^{miss}

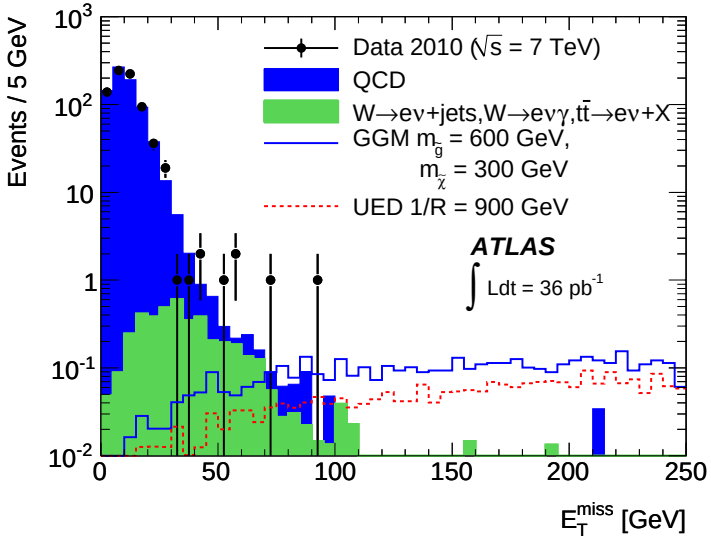
- In gauge-mediated SUSY breaking (GMSB) models, the LSP is the gravitino

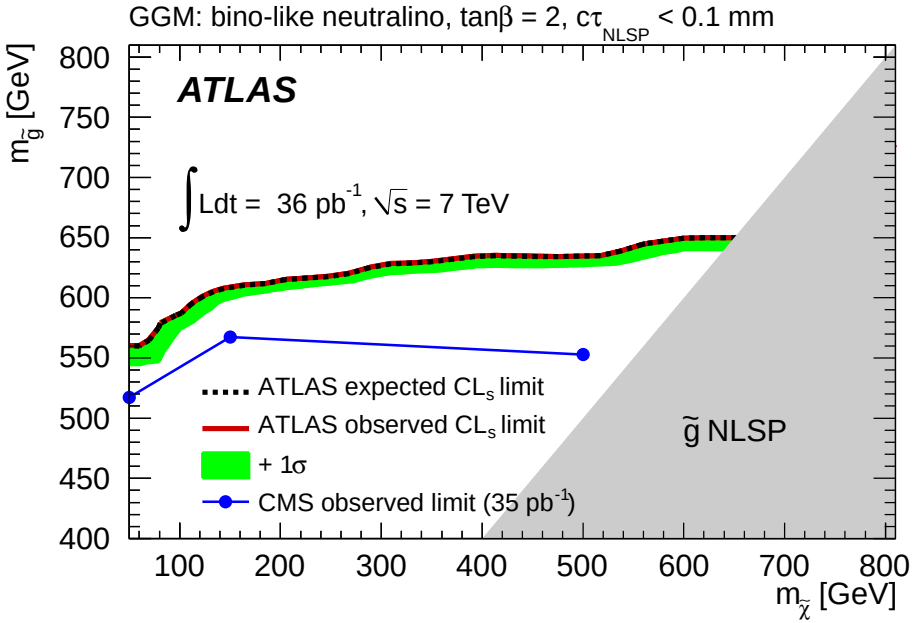
$$\chi_1^0 \to \tilde{G}\gamma$$

- Signature: $2\gamma + E_T^{miss} + X$

- Interpretation using a generalized model of gauge-mediated SUSY breaking (GGM) with a bino-like lightest neutralino (95 % C.L.)
  - σ<0.38 – 0.65 pb
  - m(gluino)>560 GeV
- Intepretation using Universal Extra Dimension (UED) (95 % C.L.)
  - σ<0.18 – 0.23 pb
  - 1/R>961 GeV on the UED compactification radius

L=36 pb^{-1}





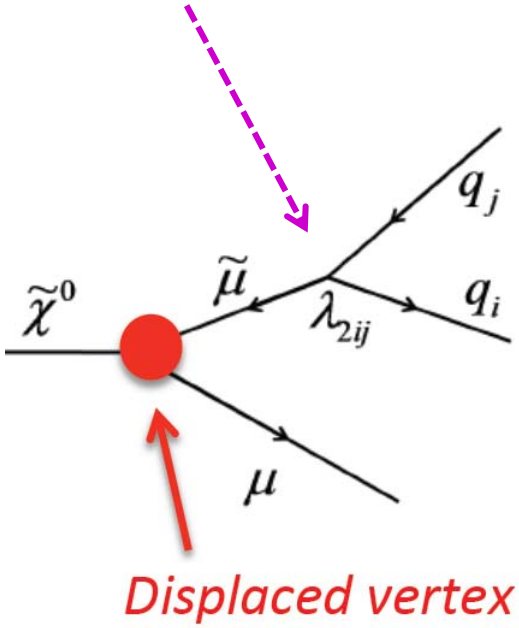
R-parity violating SUSY

Heavy long-/medium-lived particles

L=33 pb^{-1}

- Heavy stable particles are predicted in a number of theories including SUSY
  - Models with stau as the LSP
  - R-hadron (long-lived gluinos or squarks after hadronization)
  - SUGRA with R-parity violation

R-parity violating interaction



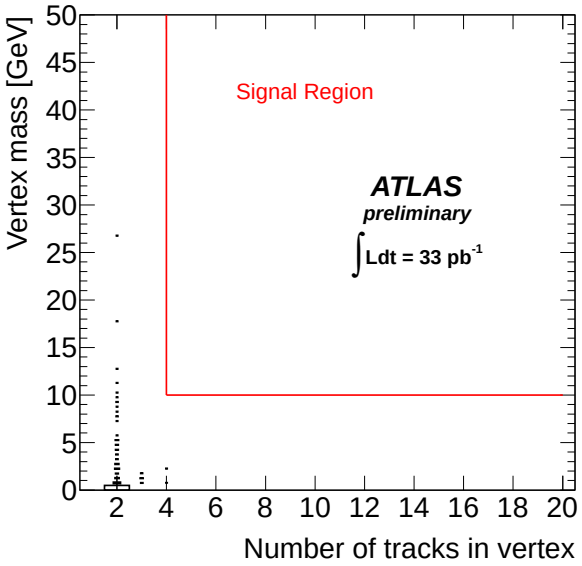
Event selection

- Muon p_T>45 GeV (also used for the trigger)
- Displaced vertex (DV) using tracks with d0>2 mm
- DV fit quality : χ^2<5
- Fiducial region of the pixel detector
  - $|z_{DV}|$<300 mm, $|r_{DV}|$<180 mm
  - 3D distance from the primary vertex > 4 mm
- $N_{trk,DV} \geq 4$
- m_{DV}>10 GeV
- Veto vertices in high density material regions

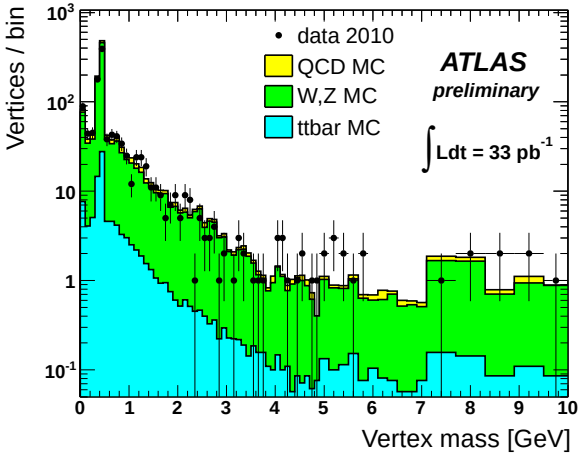
Results on medium-lived particle search

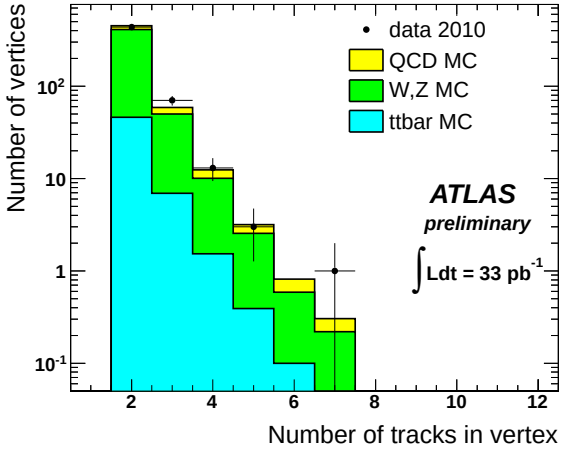
- No signal observed
- Set limit on the cross section
  - σ·acceptance·ε<0.09 pb @ 95 % C.L.

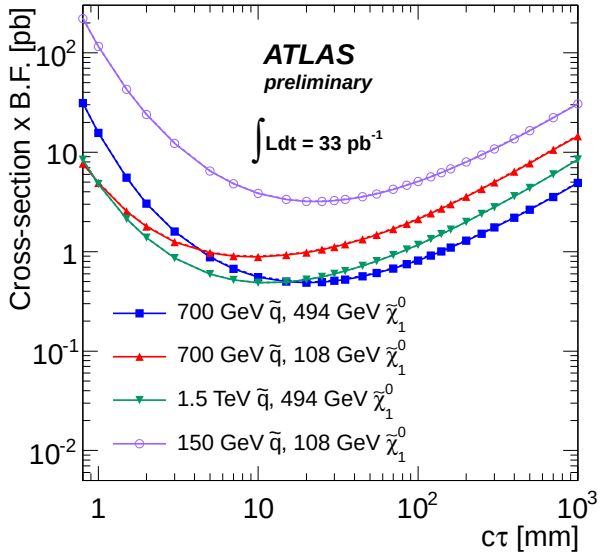
  for m(squark)=150 GeV and 100 % branching ratio



Distributions of m_{DV} and N_{trk}



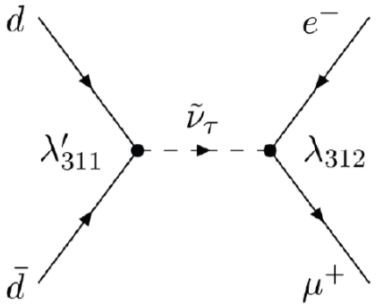




Search for e-μ resonance

NEW L=0.87 fb^{-1}

- Look for particles decaying into opposite-sign different flavor lepton
  - R-parity violating SUSY
  - Extra Z' gauge boson with lepton flavor violation
- High mass e-μ pair: clear signal with small SM contribution



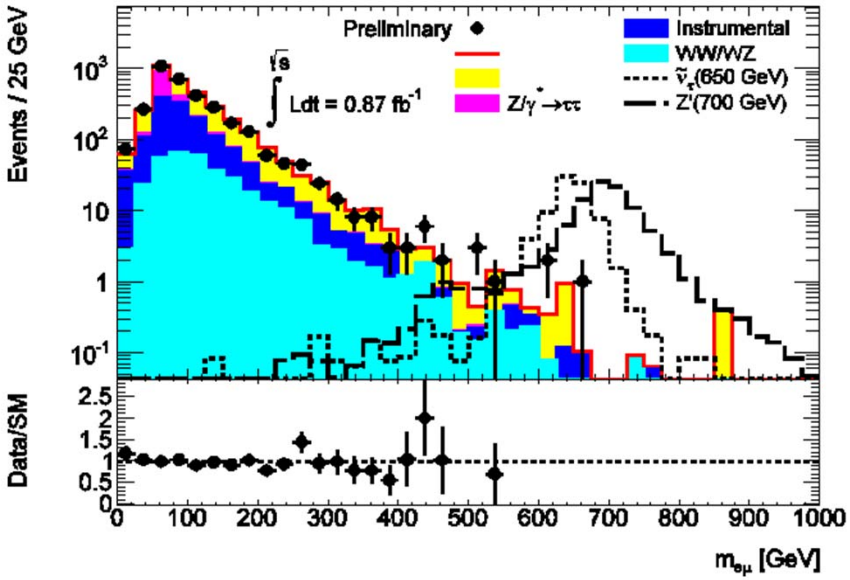
$$\text{Lagrangian term}: \frac{1}{2}\lambda_{ijk}L_iL_jE_k + \lambda'_{ijk}L_iQ_jD_k$$

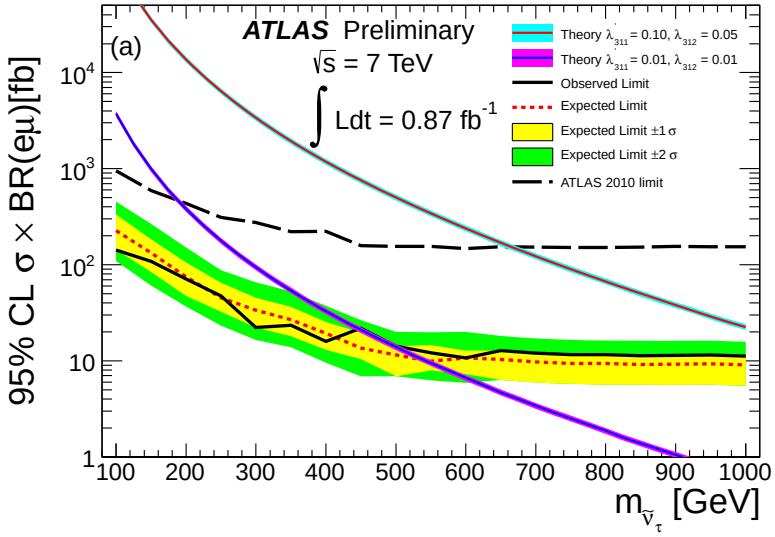
L / Q : lepton/quark SU(2) double superfield

E / D : charged lepton/down - type quark singlet

Process	Number of events
$Z/\gamma^* \to \tau\tau$	614 ± 53
$t\bar{t}$	1281 ± 168
WW	318 ± 24
Single top	125 ± 17
WZ	18.2 ± 1.9
$W/Z + \gamma$	67 ± 11
Jet instrumental background	984 ± 105
Total background	3408 ± 230
Data	3338

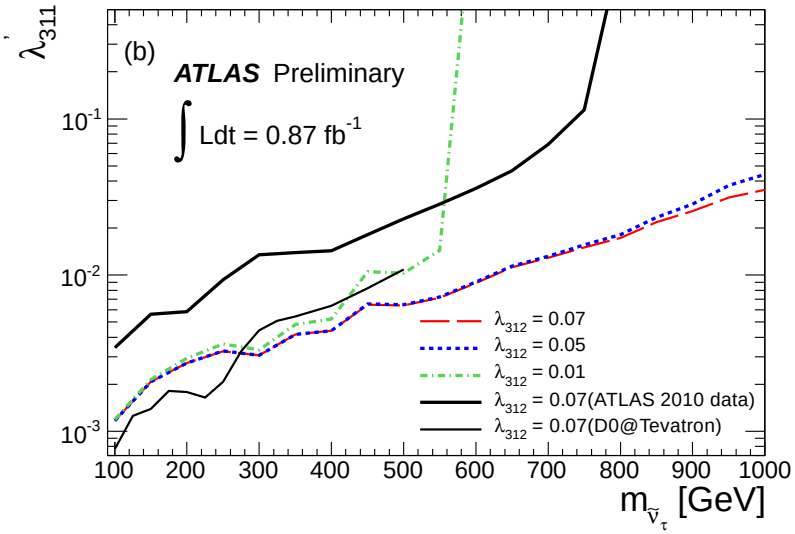
Limits from e-μ resonance search





Limit on the cross section * BR

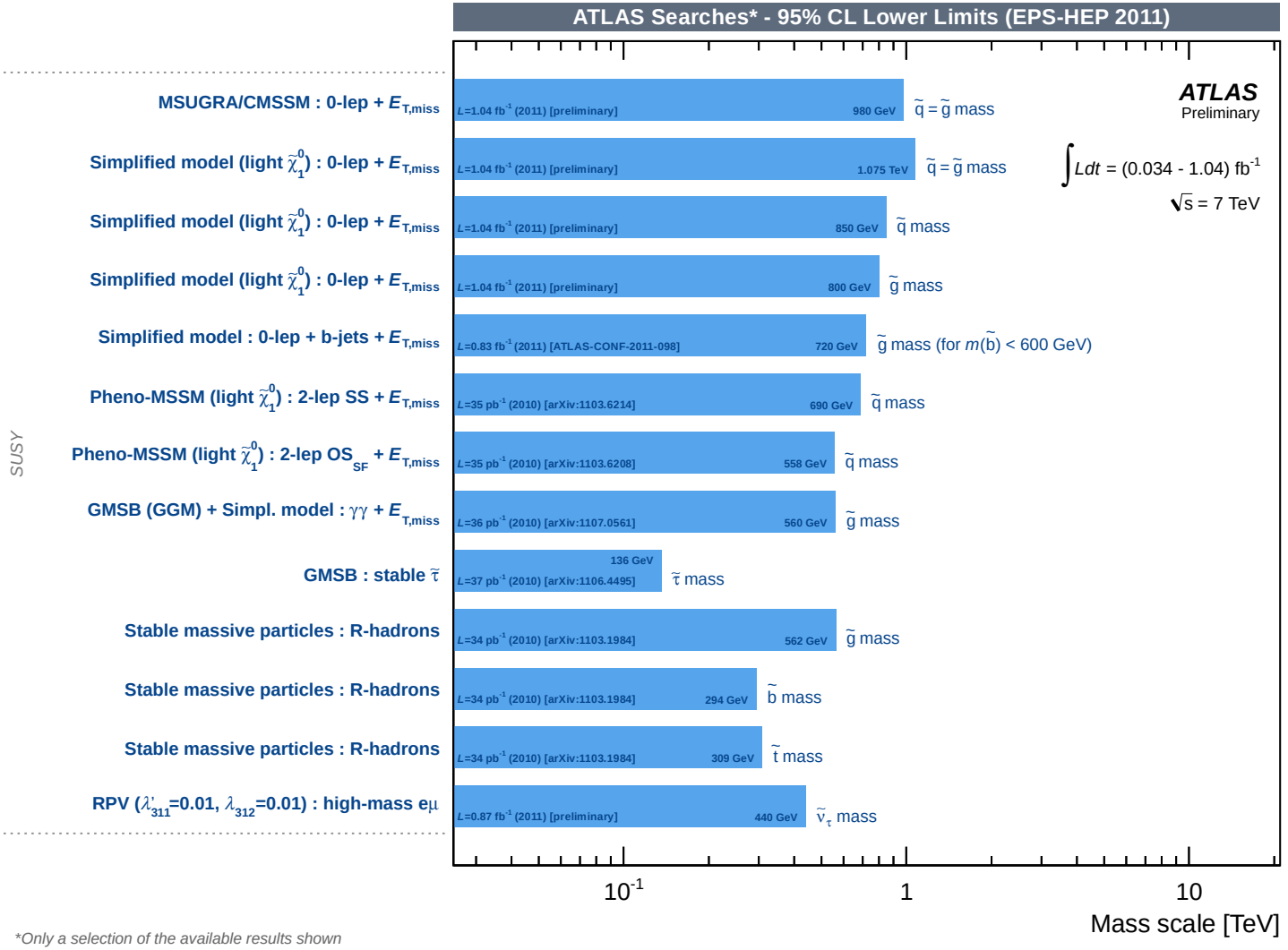
$$\sigma(pp \to \tilde{\nu}_\tau) \cdot BR(\tilde{\nu}_\tau \to e\mu)$$



$\sigma \leq 130$ fb for $m_{\nu_\tau} = 100$ GeV

≤ 11 fb for $m_{\nu_\tau} = 1$ TeV

Summary of ATLAS SUSY limits



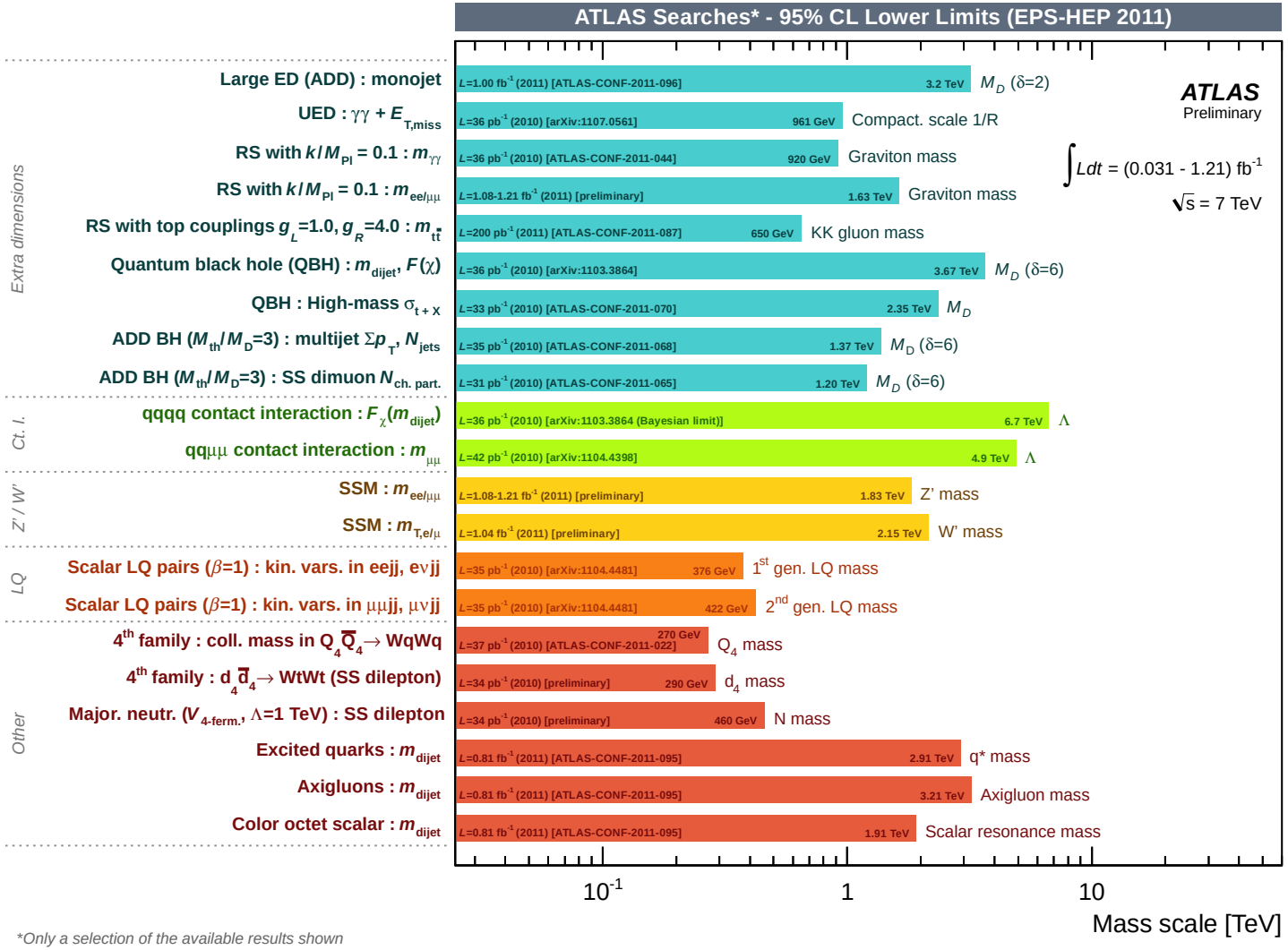
*Only a selection of the available results shown

Conclusion

- Many searches for new physics are being performed in ATLAS and already many of them have been published
  - Concentrated on new results shown at EPS
  - Some analyses using ~1 fb^{-1} of data (0-lepton, 0-lepton+bjet, eμ resonance)
- No excess was observed over SM expectation and derived 95 % C.L. exclusion limits
  - 0-lepton + E_T^{miss} channel excludes gluino/squark masses up to ~1 TeV
- Expect to have 3-5 times more data by the end of 2011 and even more in 2012
  - Increase the reach towards higher masses and into other regions in the parameter space

Backup slides

Summary of ATLAS limits (exotics)



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