Update on ATLAS SUSY Searches

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LHC Physics Discussion Meeting
Hamburg, October 24th, 2011

Outline

> **>** introduction

> **>** updates since summer

  - missing transverse momentum with large number of multiple jets

  - missing transverse momentum with jets and one lepton

  - missing transverse momentum with one b-jet, jets and one lepton

  - missing transverse momentum with 2 photons

> **>** summary

Search Strategies for SUSY

> **at the LHC sparticles are pair produced**

- dominantly squarks and gluinos via the strong interaction

- they decay via cascades into the stable LSP (neutralino or gravitino), assuming R-parity conservation

> **common signature:**

- multiple, high energetic jets and transverse missing momentum

- distinguish final states by additional particles

  zero, one, two, .. leptons (e, μ), two photons, …
  b-jets if 3rd generation squarks are lighter than other generation squarks

> **incomplete event reconstruction due to LSP**

- no mass peak
  $\rightarrow$ SUSY is in the tails of the distributions

- SM backgrounds (top, W/Z+jets, QCD) are taken from/verified in control regions
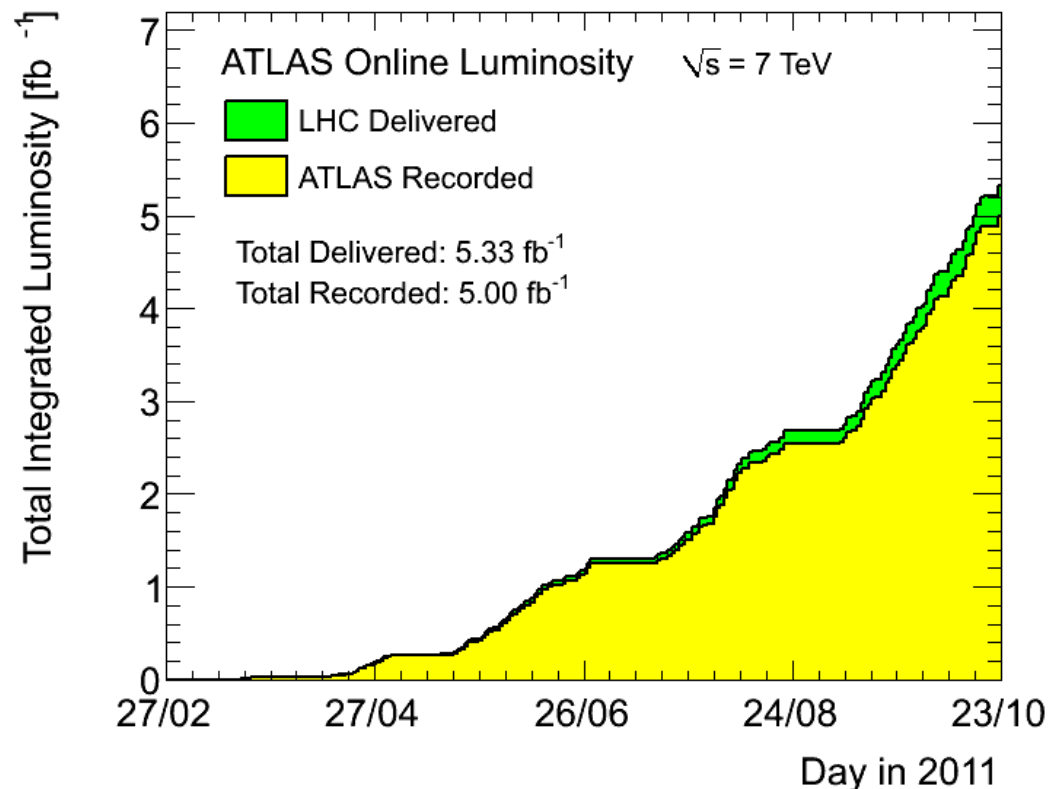
0-lepton

1-lepton

2-leptons
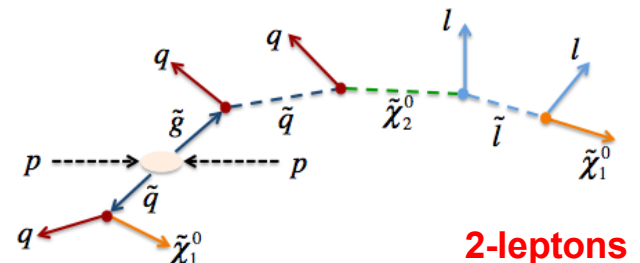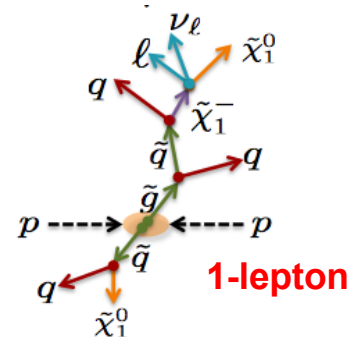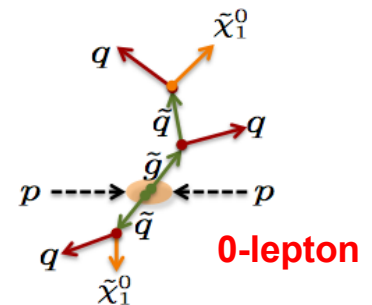
A Word on Models

> most experimental results are interpreted in one or the other model

  - e.g. mSUGRA/CMSSM, GMSB, simplified models, …

  - the interpretation in a model give nice, coloured plots

> the main experimental result is the limit on the number of signal events in the signal region (or the limit on the effective cross section)

> interpretation is straight forward but not trivial

  - signal efficiency

  - signal uncertainties

  - statistical interpretation

> mSUGRA/CMSSM:

  - m_0: common scalar mass

  - $m_{1/2}$: common gaugino mass

  - A_0: common trilinear coupling

  - $\tan \beta$: ratio of Higgs vacuum expectation values

  - $sign(\mu)$: sign of SUSY Higgs potential parameter

> GMSB:

  - Λ: SUSY breaking scale

  - M: messenger mass scale

  - N: number of messenger fields

  - $\tan \beta$: ratio of Higgs vacuum expectation values

  - $sign(\mu)$: sign of SUSY Higgs potential parameter

  - C_{grav}: ratio of the gravitino mass to its value at the breaking scale Λ

> Simplified models:

  - reduced particle spectrum: masses

The Large Hadron Collider

> pp collisions at √s = 7 TeV

> LHC has performed extremely well this year:

- 3.59 x 10^{33} /cm^2/s peak luminosity

- ~ 80 pb^{-1} per day

- >5 fb^{-1} delivered, thanks!

- 50 ns bunch spacing

- ~15 collisions per crossing

> datasets considered by analysis up to now

- 2011: 0.87 – 1.34 fb^{-1}

ATLAS SUSY Searches

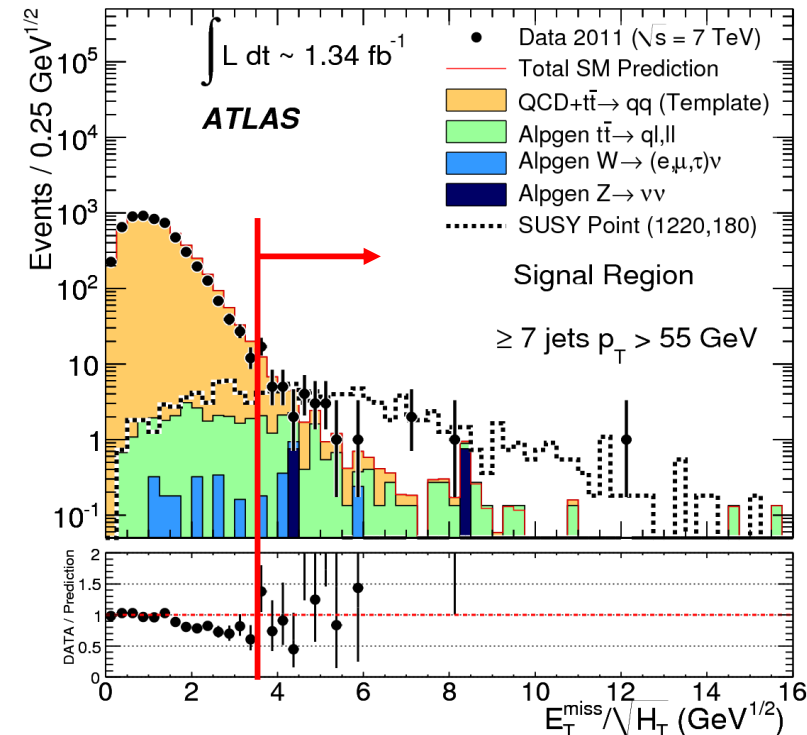| ATLAS SUSY analyses	Publications
E_T^{miss} + jets + 0 lepton	arXiv:1102:5290 (35 pb^{-1}) [published in PLB]; ATL-CONF-2011-086 (163 pb^{-1}); arXiv:1109.6572 (1.04 fb^{-1}) [submitted to PLB]
E_T^{miss} + multiple jets + 0 lepton	*New* arXiv:1110.2299 (1.34 fb^{-1}) [accepted by JHEP]
E_T^{miss} + jets + 1 lepton	arXiv:1102:2357 (35pb^{-1}) [PRL]; ATL-CONF-2011-090 (163 pb^{-1}); arXiv:1109.6606 (1.04 fb^{-1}) [submitted to PRD]
E_T^{miss} + b jets + 0/1 lepton	arXiv:1103:4344 (35 pb^{-1}) [PLB]; ATL-CONF-2011-098 (833 pb^{-1}); ATL-CONF-2011-130 (1.03 fb^{-1})
E_T^{miss} + jets + 2 leptons (OS, SS, SF subtraction)	arXiv:1103:6214 (35 pb^{-1}) [EPJC]; arXiv:1103:6208 (35 pb^{-1}) [EPJC]; ATL-CONF-2011-091 (simplified model interpretation to SS); preliminary (1.04 fb^{-1})
E_T^{miss} + jets + >= 3 leptons	ATL-CONF-2011-039 (34 pb^{-1})
E_T^{miss} +γγ	arXiv:1107:0561 (36 pb^{-1}) [EPJC]; preliminary (1.04 fb^{-1})
colored scalars	*New* arXiv:1110.2693 (34 pb^{-1}) [submitted to EPJC]
eμ resonance (RPV)	arXiv:1103:5559 (35 pb^{-1}) [PRL]; ATL-CONF-2011-109 (870 pb^{-1}); arXiv:1109.3089 (1 fb^{-1}) [submitted to EPJC]
Stable hadronising squarks & gluinos	arXiv:1103:1984 (34 pb^{-1}) [PLB];
Heavy long-lived charged particles	arXiv:1106:4495 (37 pb^{-1}) [submitted to PLB];
Heavy medium-lived particles	*New* preliminary (33 pb^{-1})

> use jets + missing E$_T$ analysis and increase number of jets: **6, 7 or 8**

> selection:

  - similar to standard jet + missing E$_T$ analysis

  - events with jets and missing E$_T$ → veto events with p$_T$ of e(μ) > 20(10) GeV

> four signal regions used based on the number of jets and missing E$_T$/sqrt(H$_T$)

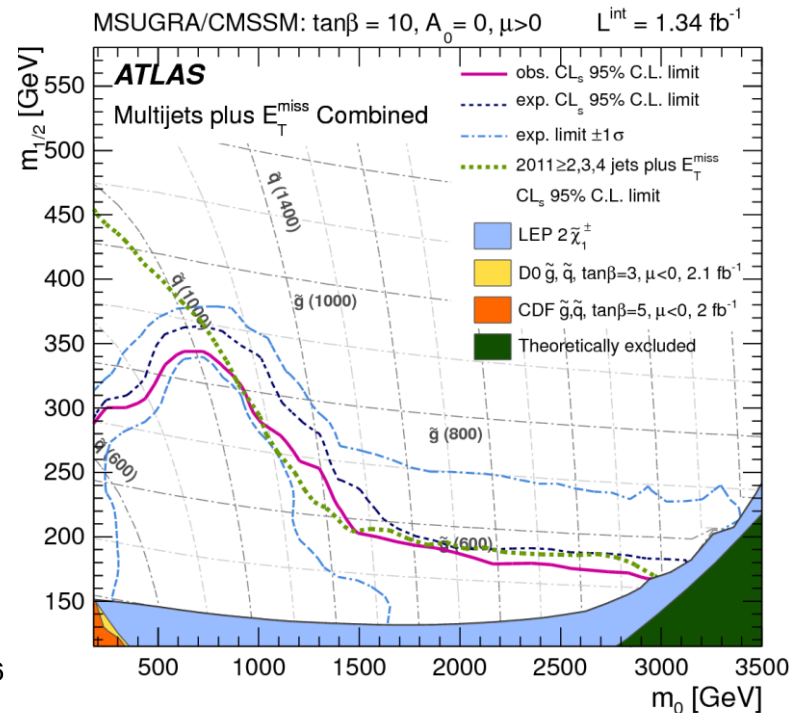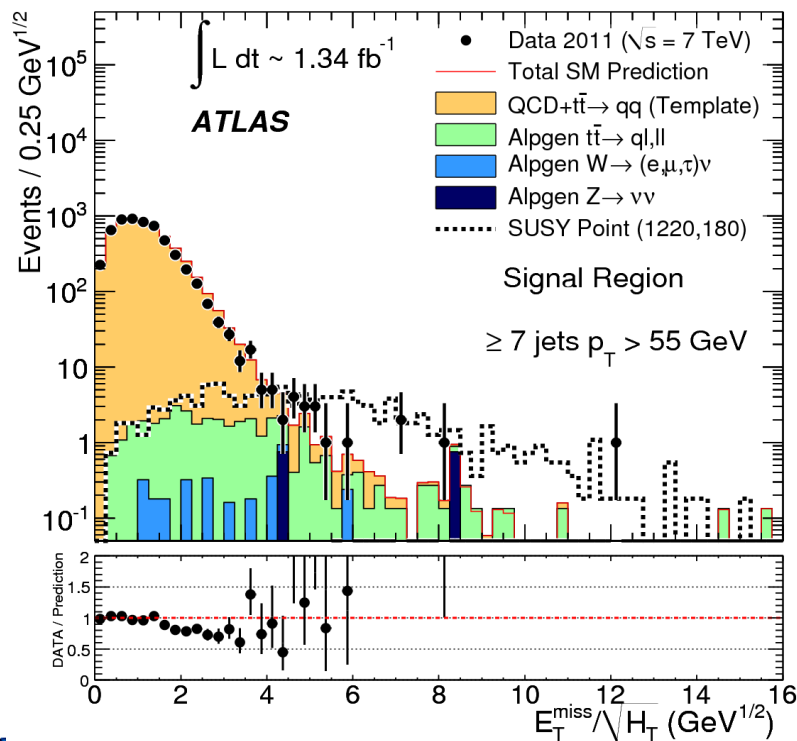 - scalar mass H$_T$ = scalar sum of all jet E$_T$

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$^{1/2}$			

$\int L \, dt \sim 1.34 \text{ fb}^{-1}$

ATLAS

- Data 2011 ($\sqrt{s}$ = 7 TeV)
- Total SM Prediction
- QCD+t$\bar{t}$→ qq (Template)
- Alpgen t$\bar{t}$→ ql,ll
- Alpgen W→ (e,μ,τ)ν
- Alpgen Z→ $\nu\nu$
- SUSY Point (1220,180)

Signal Region

≥ 7 jets p$_T$ > 55 GeV

> QCD control region defined by lower number of jets, e.g. 7 → 5 jets, and inverse cut on missing E_T/sqrt(H_T)

- essential to estimate QCD background from data as MC predictions are unreliable

- other background estimated from MC and validated in different data control regions

> signal region defined by number of jets and MET/sqrt(H_T)
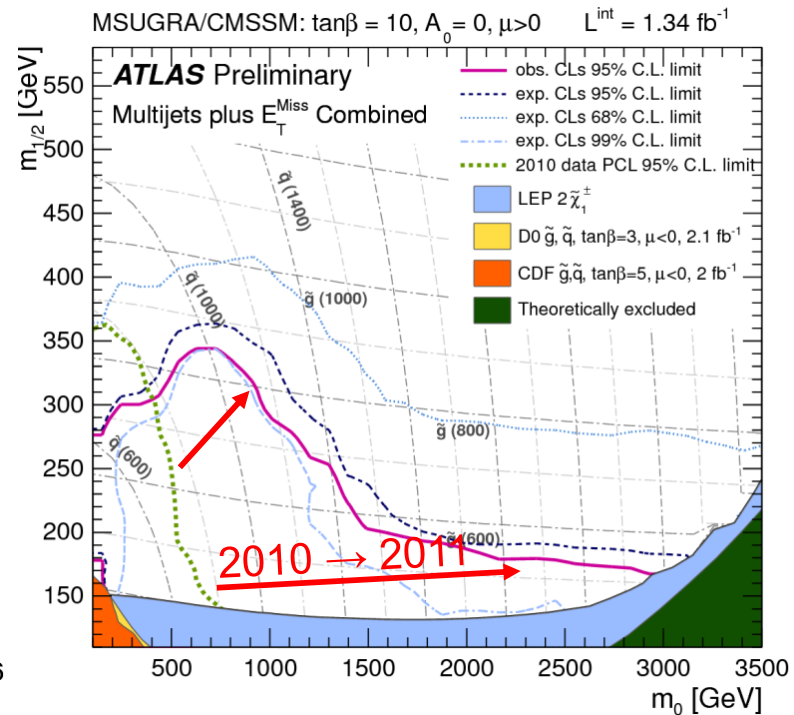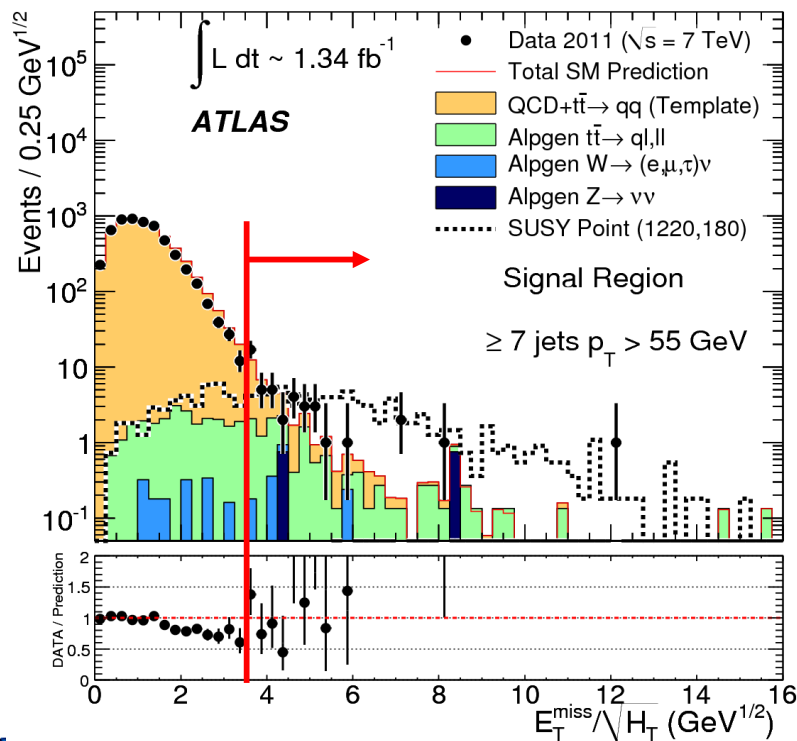
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> signal region defined by number of jets and MET/sqrt(H_T)

> 3rd generation is special: has to be light to stabilize the Higgs

> selection similar to jets + missing E_T plus 1 or 2 b-tags

> define 4 signal regions / two control regions and combine them for the exclusion limit
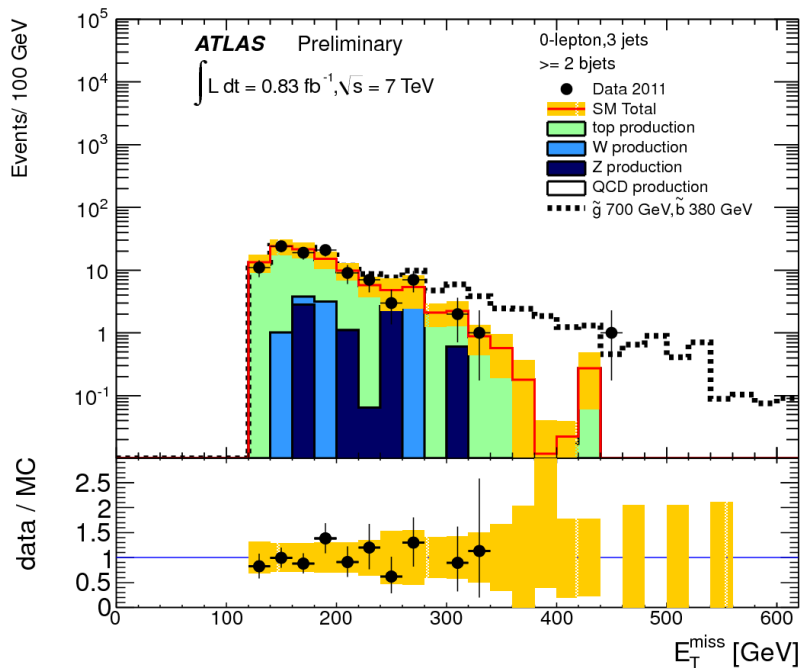
Phenomenological MSSM:
$BR(g \to b_1 b \to bb\chi^0_1) = 100\%$
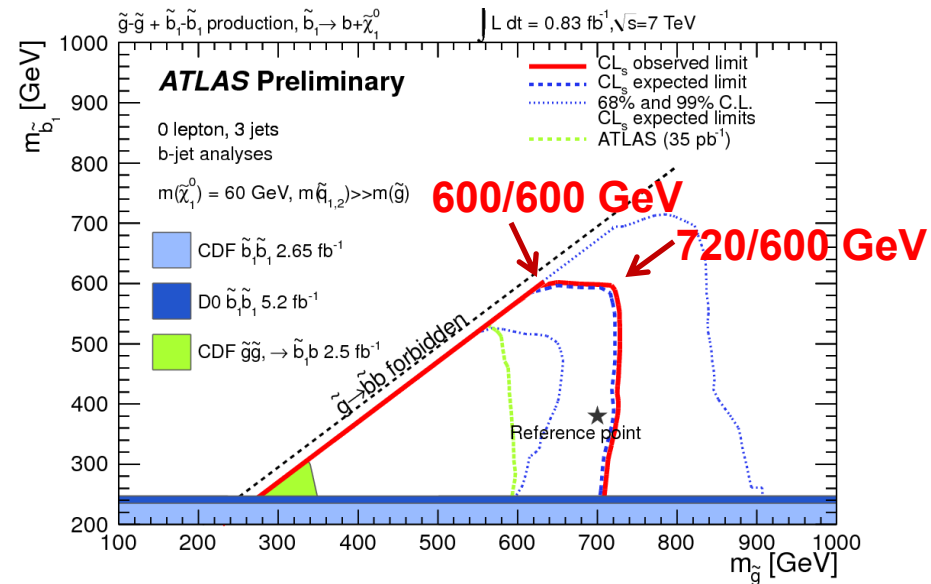
> cascades including charginos or neutralinos can lead to final states with one, two, three or more isolated leptons

> advantage: suppress QCD background, help in trigger

> analysis requires exactly 1 lepton (e: p_T > 25 GeV or μ: p_T > 20 GeV) and ≥ 3/4 jets → four signal regions
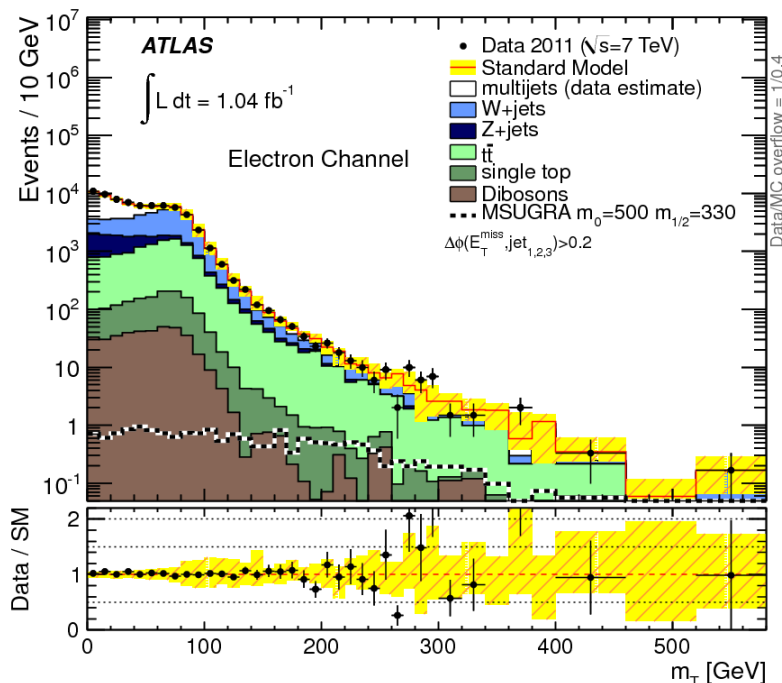
Background
- fake leptons from QCD background
→ fully data driven estimate with "loose-tight matrix method"

- non QCD background dominated by top pairs and W+jets
→ semi-data driven estimate
  - normalize MC to data in background specific CR
  - extrapolate to the signal region relying on MC shapes
  - final background estimate done performing a simultaneous likelihood fit of the different CR

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

> observed number of events in data consistent with SM

> uncertainties dominated by jet energy scale and resolution, theory and MC modeling and statistics

> interpretation in:

- mSUGRA/CMSSM $(m_0, m_{1/2})$-plane

- simplified model
  gluino → chargino → neutralino
  squark → chargino → neutralino

- bilinear R-parity violation model

Simplified model:
gluino → chargino → neutralino
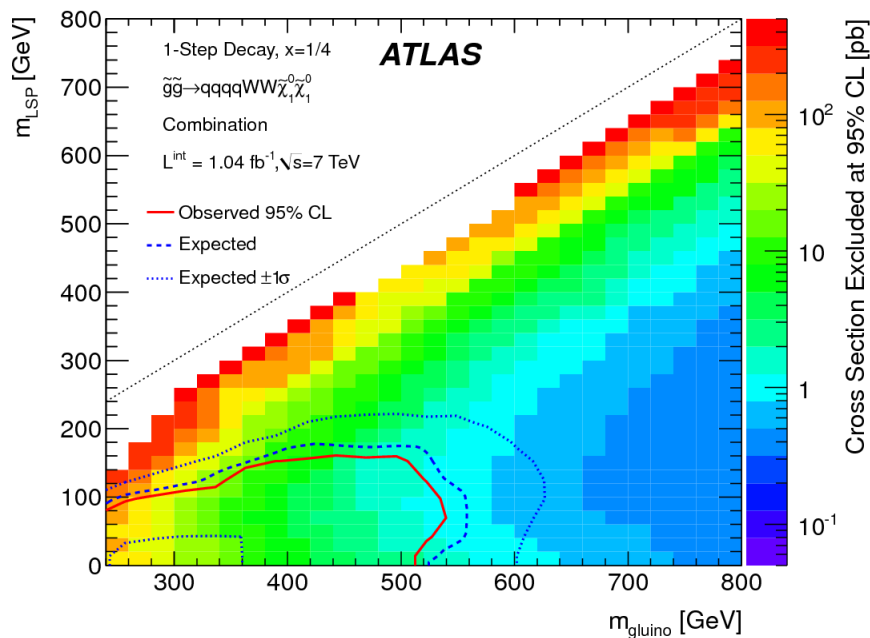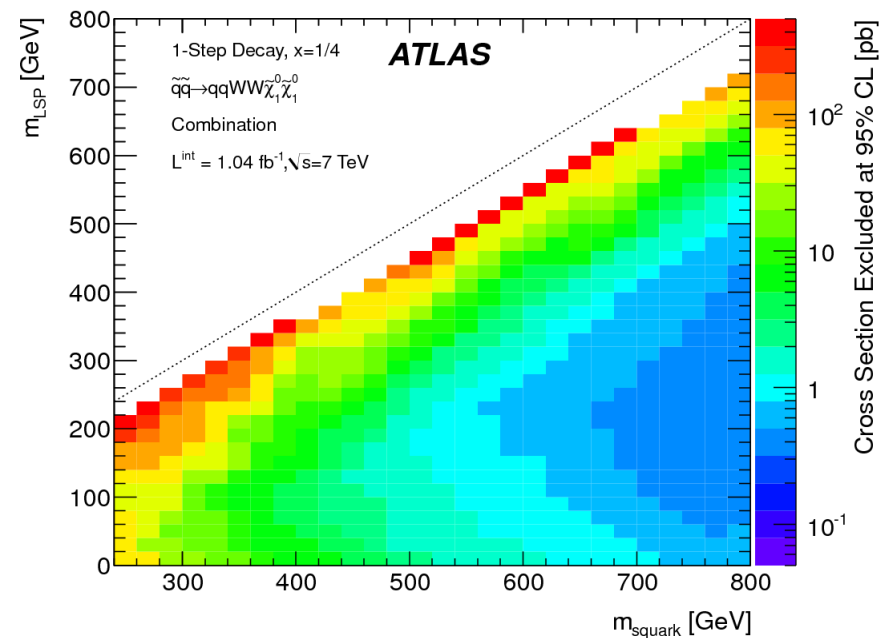
Simplified model:
squark → chargino → neutralino
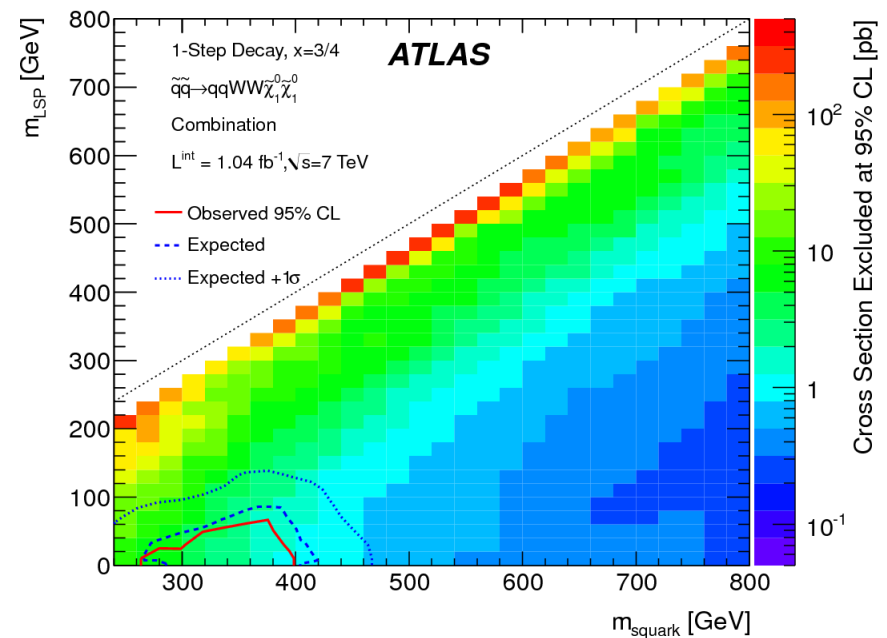
$$x = (m_{\tilde{\chi}^\pm} - m_{\tilde{\chi}^0})/(m_{\tilde{q}/\tilde{g}} - m_{\tilde{\chi}^0})$$

Simplified model:
gluino → chargino → neutralino
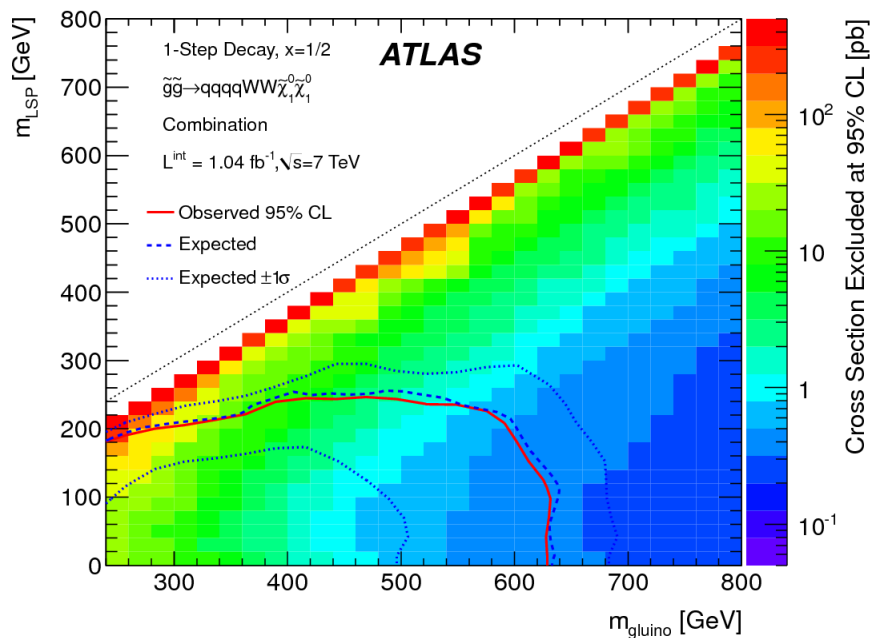
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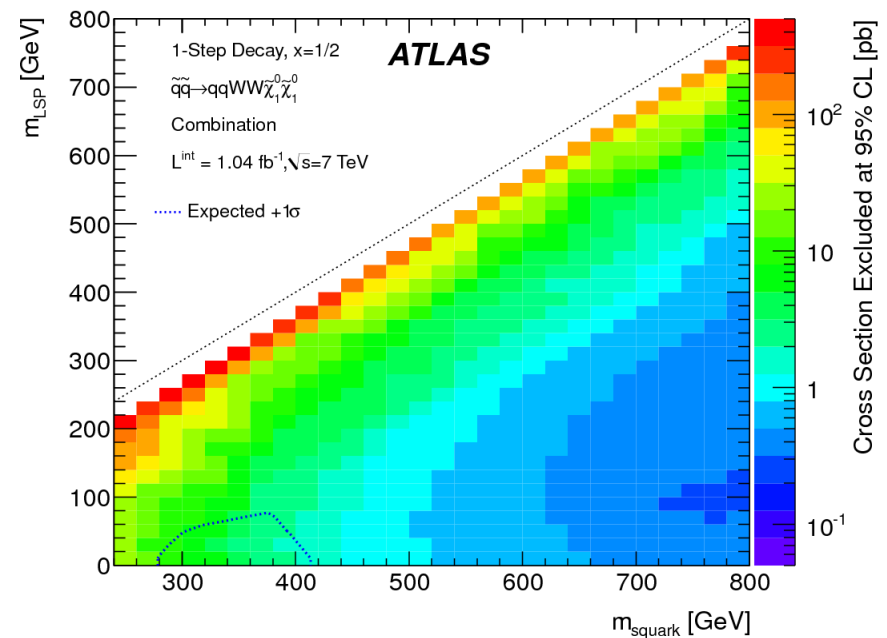
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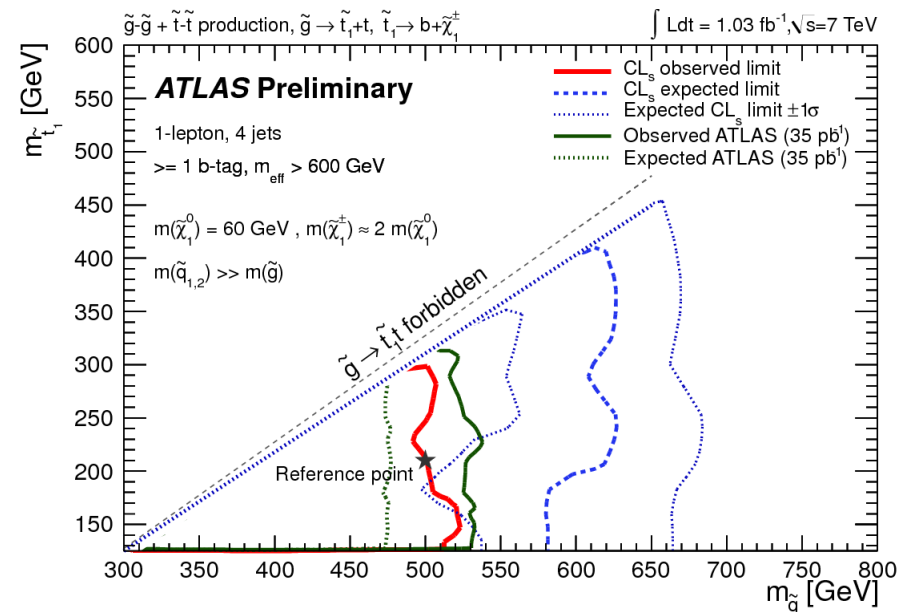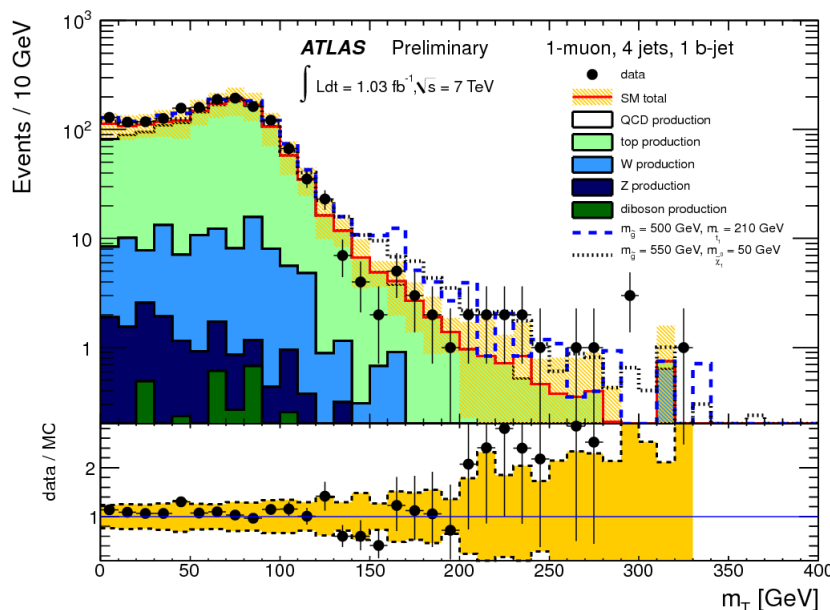squark → chargino → neutralino

$$x = \left(m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}^0} \right) / \left(m_{\tilde{q}/\tilde{g}} - m_{\tilde{\chi}^0} \right)$$

> 3rd generation is special: has to be light to stabilize the Higgs

> selection similar to one lepton + 4 jets + missing E_T plus 1 b-tags

> signal region defined by missing E_T > 80 GeV, m_T > 100 GeV and m_{eff} > 600 GeV

Phenomenological MSSM:
BR($g \rightarrow t_1 t \rightarrow tb\chi^{\pm}_1$) = 100%

> ## Gauge Mediated SUSY Breaking (GMSB)

- the very light gravitino is the LSP

- event topology defined by next to lightest sparticle (NLSP)

- large parameter space has neutralino NLSP: neutralino decays to photon and gravitino

> ## final state: diphoton (+ jets) + MET

- 2 photons (E$_T$ > 25 GeV)

- missing E$_T$ > 125 GeV

- QCD and EW background estimated from control regions, irreducible background from MC

> ## result:

- observed events: 5

- expected events: 4.1 ± 0.6 ± 1.6
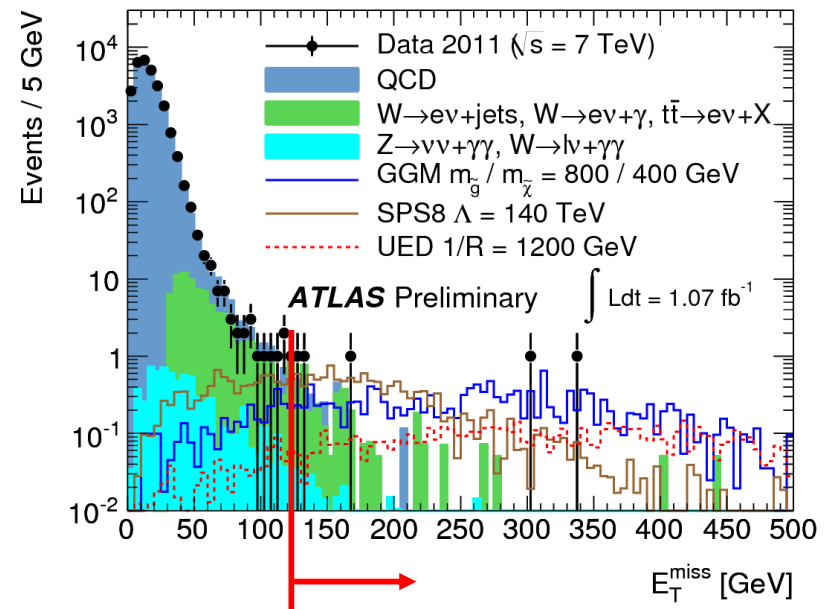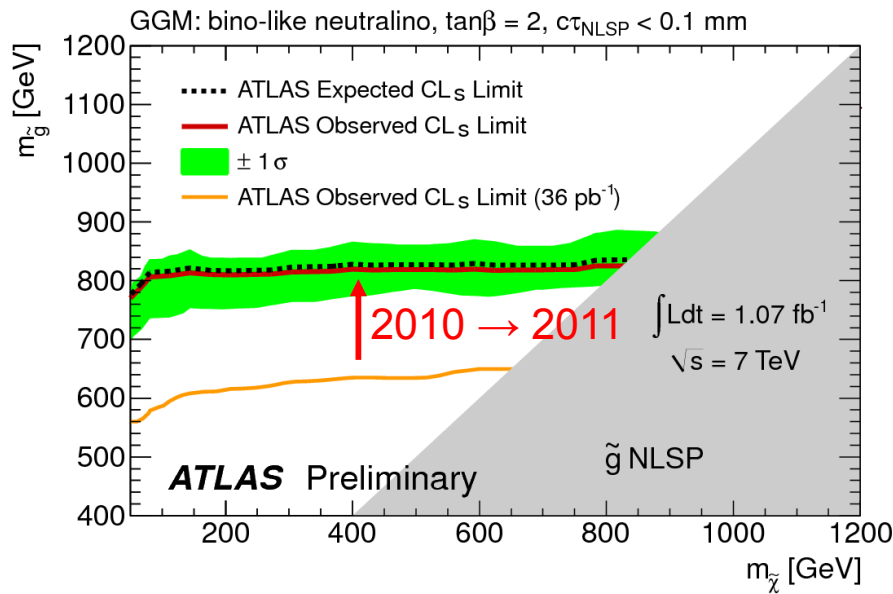
> ## General Gauge Mediation (GGM)

- simplified model with three sparticles:
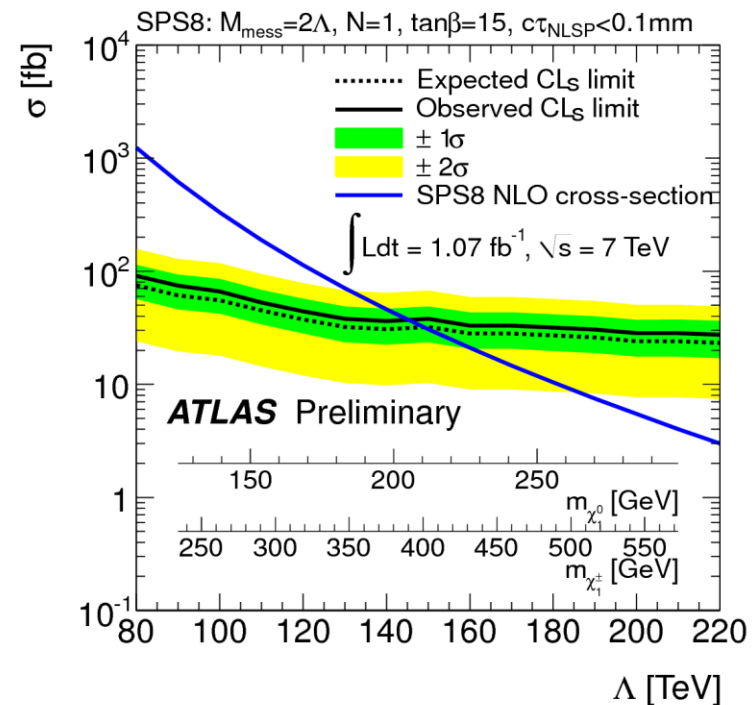
  Gluino for production
  Bino-like neutralino as NLSP

- m(gluino) < 776 GeV
  for m(neutralino) = 50 GeV

> ## minimal GMSB / SPS8 slope

- full mass spectrum

- first time considered at the LHC

- Λ < 145 TeV excluded
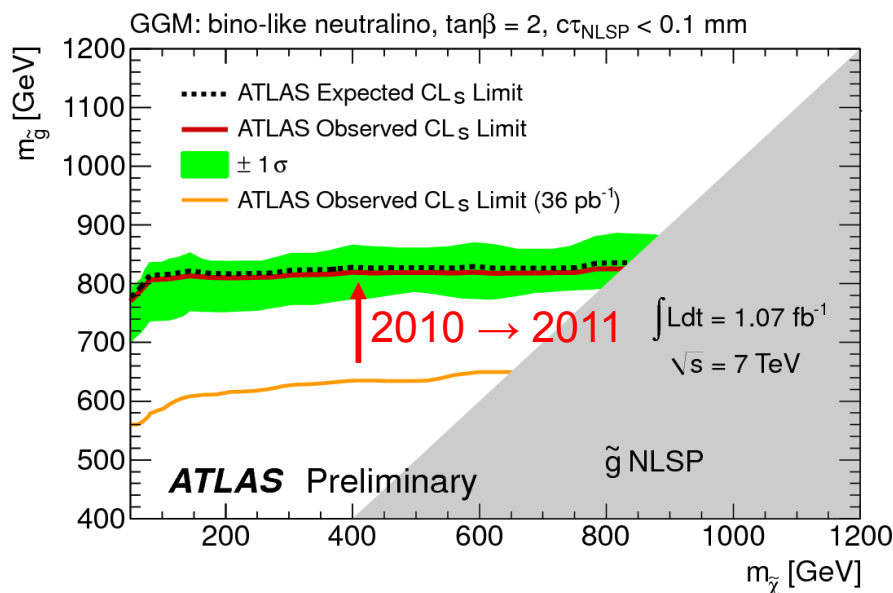
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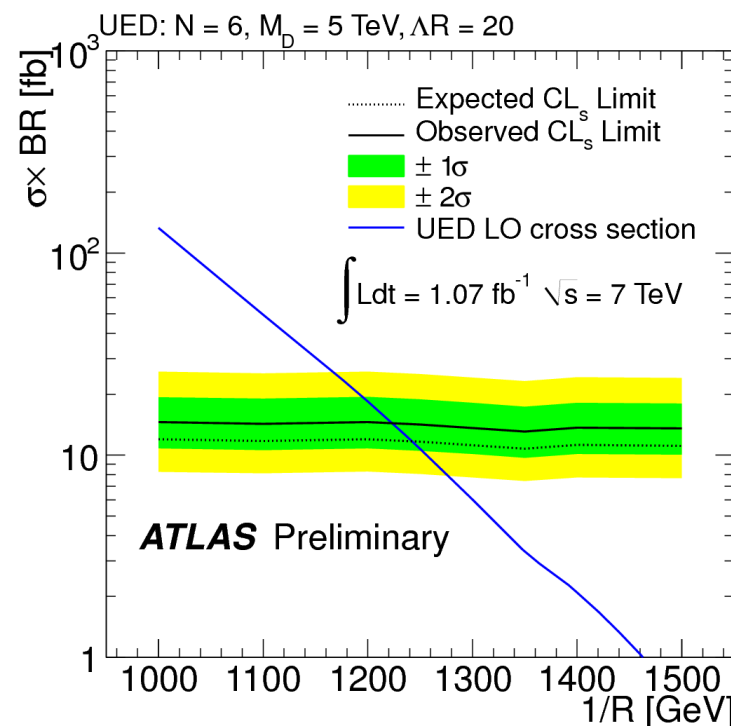
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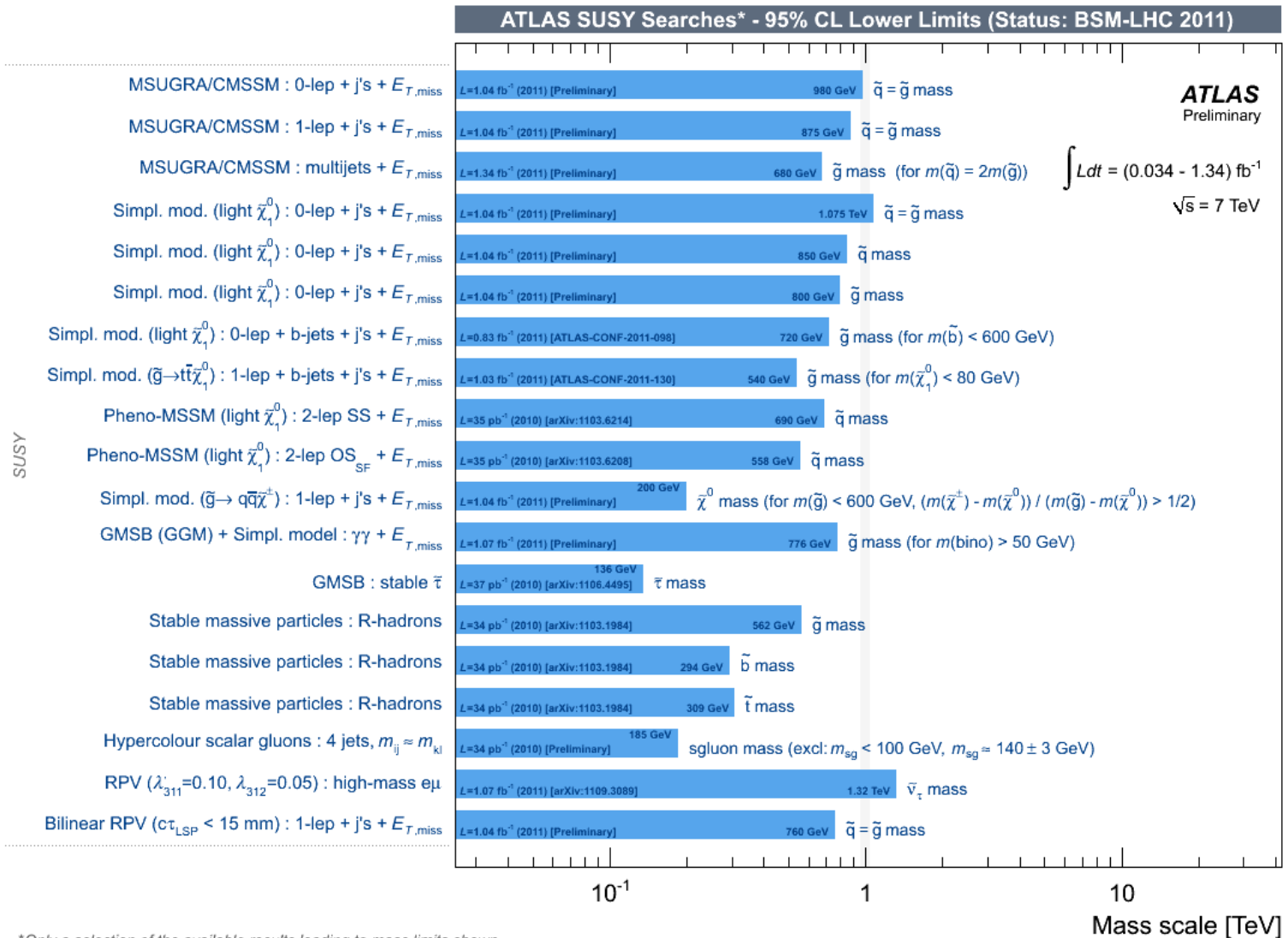> ## Universal Extra Dimension (UED)

- mass spectrum similar to SUSY

- 1/R < 1224 GeV excluded

Search generic enough for different models!

Summary of ATLAS SUSY Searches

Conclusion and Outlook

> ATLAS has produced an impressive number of papers/conference notes using the 2010 and 2011 data

> in the channels searched so far, no significant excess above the Standard Model was found

> SUSY was not "just around the corner"

> several limits have surpassed those from Tevatron/LEP

> besides MSUGRA/CMSSM also simplified models considered

> more data still to come in 2011 (already around 4.9 fb^{-1} on tape) and then there is 2012