SUSY searches in ATLAS

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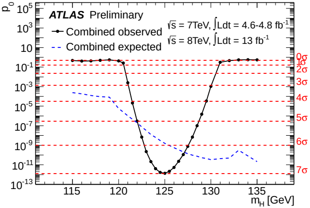
on behalf of the ATLAS collaboration

Introduction

The LHC

Living up to the historical tradition of hadronic colliders : discovery machines.

Delivering highest luminosity and collision energy ever $\Rightarrow$ a whole new mass scale.



Supersymmetry production

ATLAS has been focusing on searches for the weak scale supersymmetry in different and diverse scenarios

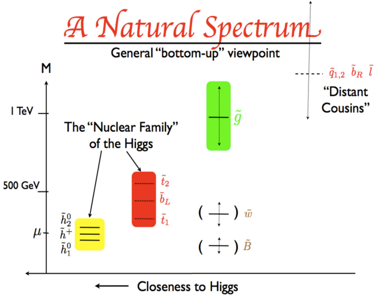
- inclusive and dedicated analyses for gluinos, squarks, gauginos, sleptons, long-lived particles, etc,
- R-parity conservation and violation.

SUSY searches in ATLAS

Natural SUSY spectrum

The stabilisation of the Higgs boson mass can be achieved if the typical mass of squarks and gluinos is around the TeV scale.

As the top and bottom quarks are heavy, the mass scale of the lighter superpartners in the third family might stay below the TeV level.



Ref : L. Hall, LBL workshop, 21 Oct 2011

Outline of the talk : selected topics, various final states, $\int Ldt = 5.8 - 12.8\ \text{fb}^{-1}$ @ 8 TeV

Inclusive squarks and gluinos, *dedicated light scalar top and bottom* searches : all jets, b-jets, lepton(s) and jets,

Long-lived particles, *scalar gluon* and *R-parity-violating gluino* multijet searches.

Other searches

MSSM Higgs boson and *multilepton* analyses : c.f. talks by J. A. Valls and J. Wittkowski.

General features of SUSY analyses (1/2)

R-parity

Most analyses assume R-parity conservation with the LSP being a weakly interacting particle (neutralino or gravitino) $\Rightarrow$ presence of missing transverse momentum E_T^{miss} in the final state.

Signal and background separation : exploit the signal-background mass gap whenever possible

Jet and lepton multiplicity.

Effective mass m_{eff}, hadronic transverse mass : different scalar sums of transverse momenta of identified objects in the final state (leptons, jets, E_T^{miss}).

Transverse mass m_{T2}, contransverse mass m_{CT} : exploit the mass gap between intermediate particles in the decay chain.

Other analysis-dependent variables.

General features of SUSY analyses (2/2)

Background estimation

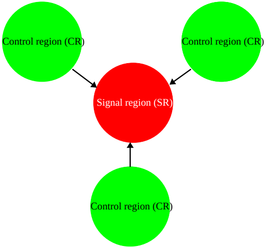
Major backgrounds : normalised using data from appropriately defined control regions (region with substantial contribution from the background of interest)

- Apply $CR \rightarrow SR$ transfer factor to predict contribution in the signal region.

Multijet and fake (irreducible) backgrounds : determined from data

- Hadronic searches : jet energy resolution smearing.
- Leptonic searches : matrix technique based on loosening the lepton identification requirement.

Smaller irreducible backgrounds : predicted by Monte Carlo only.



Limit setting

The profile likelihood ratio test in combination with CL_s used to get $CL = 95\%$ exclusion limit.

Inclusive searches : (lepton +) jets + E_T^{miss} ATLAS-CONF-2012-109/104

Signal

Squark and/or gluino pair production.

Different analyses depending on the jet and lepton multiplicity.

Main backgrounds

Top, Z+jets, W+jets : validated and estimated from a respective control region.

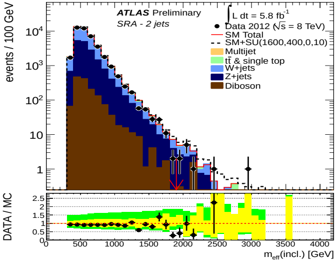
Diboson : predicted by Monte Carlo.

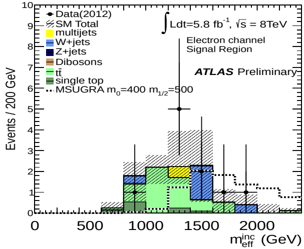
QCD multijet : estimated from data (jet smearing, matrix method) $\Rightarrow$ negligible in most cases.

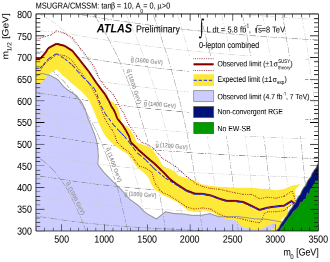
Discriminating variables

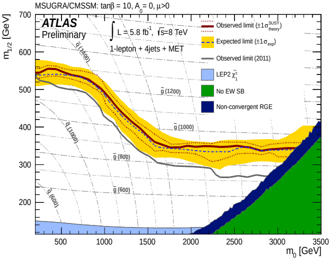
E_T^{miss}

$$m_{eff} = (p_{T,lep}) + \sum_{i=jets} p_{T,i} + E_T^{miss}$$









Limit results : MSUGRA/CMSSM model, $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$

Exclude at $CL = 95\%$ $m_{1/2} < 350$ GeV for all m_0 and $m_0 < 740$ GeV for all $m_{1/2}$ (jets + E_T^{miss} analysis).

Exclude $m_{\tilde{q}} = m_{\tilde{g}}$ below 1500 GeV (jets + E_T^{miss} search) and 1100 GeV (one lepton channel).

Signal

Gluino pair production $\tilde{g} \rightarrow \tilde{b}_1 b$ or $\tilde{g} \rightarrow \tilde{t}_1 t$.

Main backgrounds

$t\bar{t}$+jets : validated and estimated from respective control region.

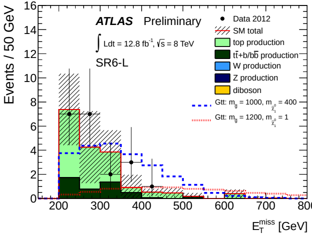
QCD multijet : estimated from data using the jet smearing technique (and cross-checked by the matrix method) $\Rightarrow$ negligible.

Other backgrounds ($t\bar{t} + b/b\bar{b}$, $t\bar{t} + W/Z$, W/Z+heavy-flavour jets) : predicted by Monte Carlo.

Discriminating variables

E_T^{miss}, several variants of m_{eff}.

$\Delta\Phi_{min}^{4l}$: minimum azimuthal separation between any of the four leading jets and E_T^{miss}.



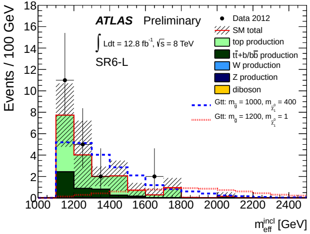
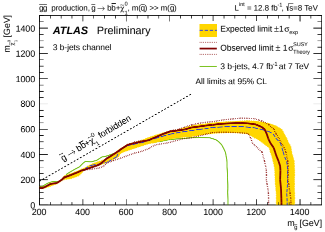
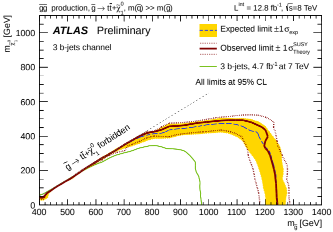


TABLE : *Fitted backgrounds in selected signal regions (SR).*

Signal region	SR4-L	SR6-L
$t\bar{t}$+jets	30 ± 6	12 ± 4
$t\bar{t} + b/b\bar{b}$	8.1 ± 8.3	4.6 ± 5.0
single top	3.5 ± 1.3	0.6 ± 0.3
$t\bar{t} + W/Z$	1.4 ± 0.8	0.8 ± 0.4
W/Z	2.6 ± 1.9	0.1 ± 0.1
Total background	46 ± 10	18 ± 6
Observed	38	20





Limit results : simplified models

Gbb model : $BR(\tilde{g} \rightarrow b\bar{b}\chi_1^0) = 100\%$

Gtt model : $BR(\tilde{g} \rightarrow t\bar{t}\chi_1^0) = 100\%$

- $m_{\chi_1^0} < 200$ GeV : exclude $\tilde{g}$ mass up to 1240 (1100) GeV in *Gbb* (*Gtt*) model.
- $m_{\tilde{g}} = 1100$ GeV : exclude χ_1^0 mass below 570 (440) GeV in *Gbb* (*Gtt*) model.

Signal

Direct light sbottom or stop pair production.

Main backgrounds

Top production, W/Z produced in association with heavy-flavour hadrons : validated and estimated from respective control regions.

QCD multijet : estimated from data using the jet smearing technique.

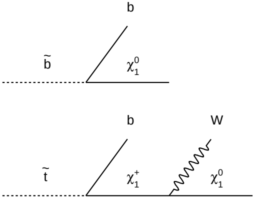
Other backgrounds : predicted by Monte Carlo.

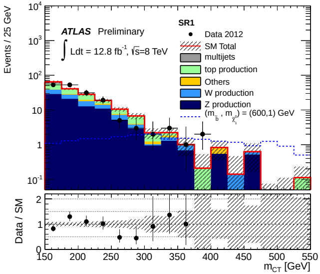
Discriminating variables

E_T^{miss}, m_{eff}

Contransverse mass

$m_{CT}^2 = [E_T(\nu_1) + E_T(\nu_2)]^2 - [\vec{p}_T(\nu_1) - \vec{p}_T(\nu_2)]^2$



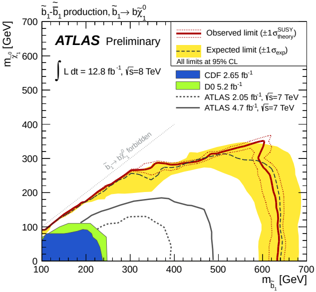


Sbottom/stop pair : two b-jets + E_T^{miss} ATLAS-CONF-2012-165/171

Limit results : sbottom pair production

Assuming $BR(\tilde{b}_1 \to b\chi_1^0) = 100\%$.

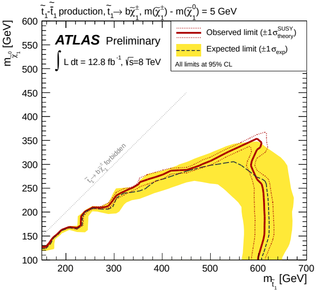
- For $m_{\chi_1^0} < 150$ GeV : exclude $\tilde{b}_1$ mass up to 620 GeV.
- For $m_{\tilde{b}_1}$ around 550 GeV : exclude χ_1^0 mass below 320 GeV.

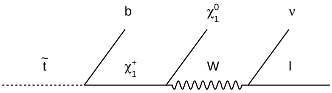


Limit results : stop pair production

Asssuming $BR(\tilde{t}_1 \to b\chi_1^{\pm}) = 100\%$ and degenerate $\chi_1^{\pm} - \chi_1^0$ masses.

- $m_{\chi_1^0} = 100$ GeV : exclude stop mass up to 580 (480) GeV for $m_{\chi_1^{\pm}} - m_{\chi_1^0} = 5$ (20) GeV.
- $m_{\tilde{t}_1} = 500$ (480) GeV : exclude χ_1^0 mass up to 300 (250) GeV for $m_{\chi_1^{\pm}} - m_{\chi_1^0} = 5$ (20) GeV.





Signal

Direct light stop pair production.

Main backgrounds

Top production, diboson : validated and estimated from respective control regions.

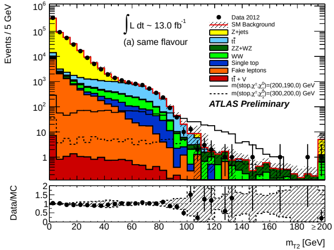
QCD multijet : estimated by the matrix technique.

Other backgrounds : predicted by MC.

Discriminating variables

Boost vector $\vec{p}_b^{ll} = \vec{E}_T^{miss} + \vec{p}_T^{l_1} + \vec{p}_T^{l_2}$.

$$m_{T2} = \min_{\vec{q}_T + \vec{r}_T = \vec{E}_T^{miss}} \left\{ \max[m_T(\vec{p}_T^{l_1}, \vec{q}_T), m_T(\vec{p}_T^{l_2}, \vec{r}_T)] \right\}$$



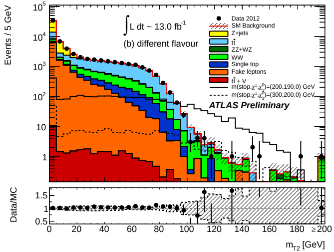
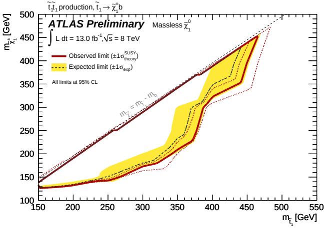
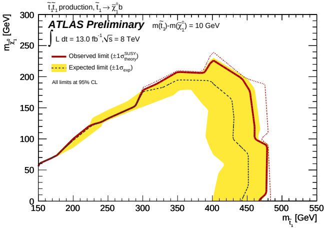


TABLE : *Fitted background events.*

Signal region	SR90	SR100	SR110
$t\bar{t}$	134 ± 24	21 ± 9	3.8 ± 1.8
Wt	11 ± 5	1.8 ± 1.9	1.4 ± 0.8
$t\bar{t} + V$	1.5 ± 0.3	0.9 ± 0.2	0.6 ± 0.2
WW	51 ± 11	23 ± 7	15 ± 5
WZ/ZZ	8.4 ± 1.9	6.3 ± 1.8	4.7 ± 1.4
Z+jets	8 ± 6	7 ± 5	4 ± 6
QCD multijet	9.6 ± 2.8	3.7 ± 1.4	1.4 ± 0.8
Total background	224 ± 31	64 ± 13	31 ± 8
Observed	178	44	22

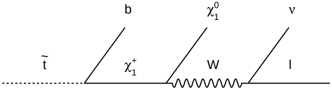


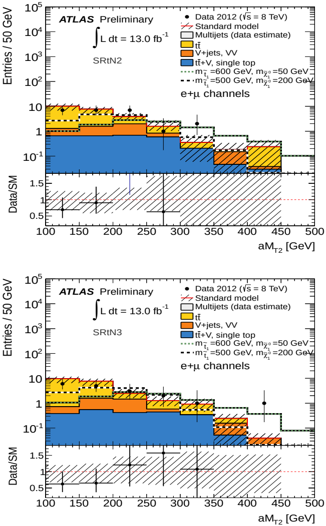


Limit results : assuming $BR(\tilde{t}_1 \rightarrow b\chi_1^+) = 100\%$ and massless neutralino

Fixing $m_{\chi_1^+} = 200$ GeV : exclude stop mass between 200 and 335 GeV.

Fixing $m_{\tilde{t}_1} - m_{\chi_1^\pm} = 10$ GeV : exclude stop mass between 150 and 450 GeV.





Signal

Direct light stop pair production.

Main backgrounds

Dileptonic $t\bar{t}$ with a non-identified lepton, W+jets : validated and estimated from respective control region.

QCD multijet : estimated by the matrix method ⇒ negligible.

Other backgrounds : predicted by Monte Carlo.

Discriminating variables

E_T^{miss}, hadronic transverse mass H_T, lepton transverse mass m_T,

Variants of m_{T2}.

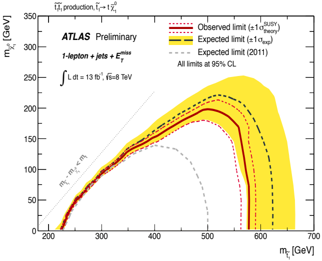
TABLE : *Fitted background events in one example signal region.*

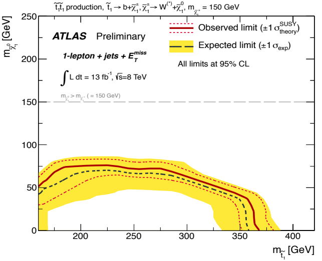
Region	SRbC	W CR	Top CR
$t\bar{t}$	260 ± 38	306 ± 94	1473 ± 99
$t\bar{t}+V$	8.9 ± 3.0	2.0 ± 0.8	10 ± 3
W+jets	37 ± 10	1231 ± 113	381 ± 78
Single top	15 ± 4	30 ± 11	140 ± 33
Z+jets, VV, multijet	4.9 ± 3.1	62 ± 38	67 ± 40
Total background	325 ± 36	1631 ± 42	2071 ± 47
Signal ($\tilde{t}_1, \chi^0, \chi^\pm$)			
= (200, 75, 150)	81.4		
= (350, 150, 300)	69.7		
Observed	314	1631	2071

Limit results : assuming massless LSP $m_{\chi_1^0} = 0$

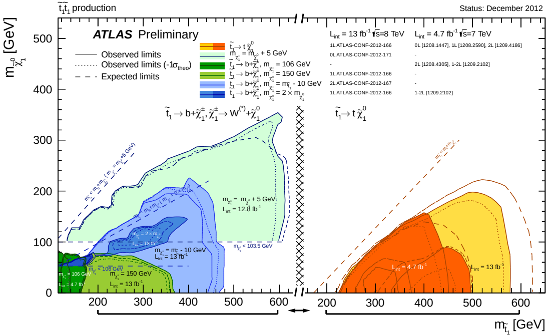
$\tilde{t}_1 \rightarrow t\chi_1^0$ scenario : stop mass excluded between 225 and 560 GeV.

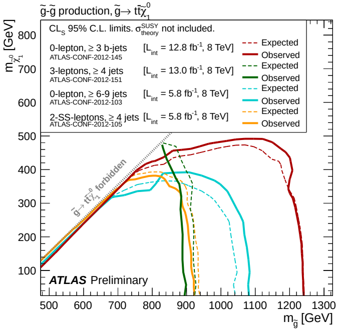
$\tilde{t}_1 \rightarrow b\chi_1^\pm$ scenario : stop mass excluded up to 350 GeV for $m_{\chi_1^\pm} = 150$ GeV.





Summary of stop pair production limit





The year 2012 was marked by a transition from inclusive squarks and gluinos searches to dedicated analyses focusing on more exclusive processes as occurred in direct stop, sbottom and also direct gaugino pair productions.

Stop searches exploit a rich spectrum of final states involving leptons, jets, b-jets and E_T^{miss} ⇒ offer sensitivity to different overlapping regions.

Signal

Sleptons, R-hadrons (composite colourless states of squarks/gluinos with quarks and gluons).

Backgrounds

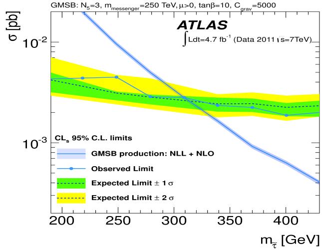
Dominated by high p_T muons with mis-measured β or large ionisation $\Rightarrow$ rejected using time-of-flight and specific ionisation energy loss dE/dx.

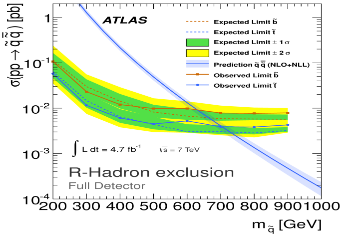
Limit results : 4.7 fb^{-1}, 7 TeV centre-of-mass.

Stop (sbottom) R-hadron : excluded up to 683 (612) GeV.

Gluino R-hadron : excluded up to 985 GeV (generic interaction model).

Staus : excluded up to 300 GeV (GMSB, $\tan\beta = 5 - 20$).

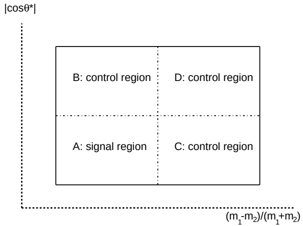




Scalar gluon pair : four-jet final state arXiv :1210.4826 [hep-ex]

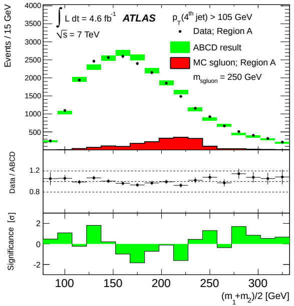
Signal : pair production of massive scalar gluons.

Background : Standard Model multijet ⇒ determined from data using the four-region ABCD method.



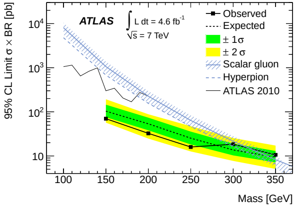
θ^* : scalar gluon scattering angle.

m_1 and m_2 : invariant masses of the two dijet systems.



Limit results : 7 TeV centre-of-mass

Combined 2010 and 2011 data : exclude scalar gluon mass between 100 and 287 GeV.



Signal : pair production of R-parity-violating gluinos
$\tilde{g} \rightarrow q\tilde{q} \rightarrow qqq$ (off-shell $\tilde{q}$).

Background : Standard Model multijet production.

Two uncorrelated analyses : resolved and boosted jet

Resolved : sensitive over large gluino mass range.

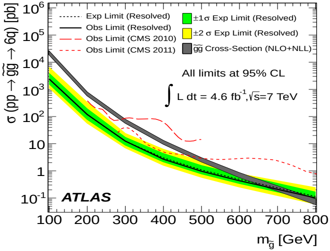
- Seek excess in jet multiplicity (*njet*) spectrum.
- Background predicted from lower *njet* bins.

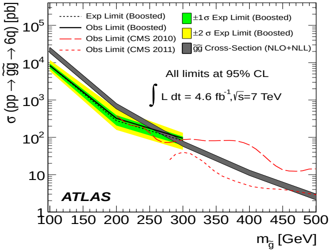
Boosted : focus on highly boosted light gluinos.

- Reconstruct large-radius jets from unresolved jets.
- Background estimated from the ABCD method (jet invariant mass and substructure as discriminating variables).

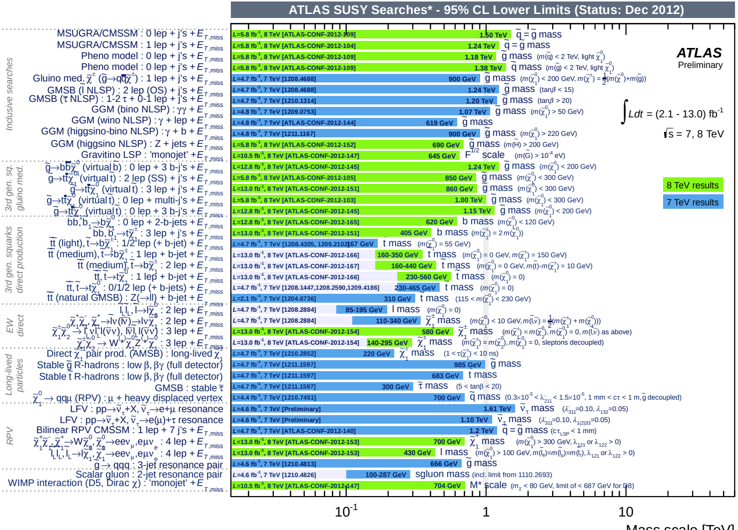
Limit results : 7 TeV centre-of-mass

Exclude gluino mass up to 666 (255) GeV in resolved (boosted) analysis.





Mass reach of ATLAS SUSY searches



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Conclusions

ATLAS has been conducting a comprehensive SUSY search program.

The individual searches are sensitive to different complementary regions of the SUSY parameter space with sufficient overlap.

Observed data has been consistent with the SM background expectation.

95% CL exclusion limits are set within various phenomenological assumptions.

$\Rightarrow$ the parameter space given by the naturalness argument is being filled up.

Results with complete 2012 data forthcoming ...

The LHC has just begun delivering Nature's secrets.