Search for SUSY in the *b*-jets plus missing transverse energy channel with and without additional lepton in ATLAS

Phenomenology 2011 Symposium

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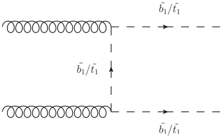
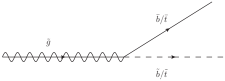
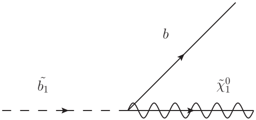
SUSY processes of interest

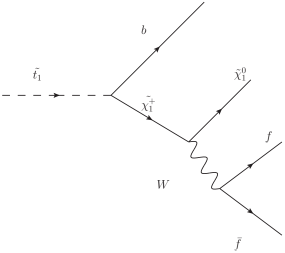
Large $\tilde{b}/\tilde{t}$ mass splitting could result in low $m(\tilde{t}_1)$ and $m(\tilde{b}_1)$
$\Rightarrow$ higher cross sections and accessibility in decay chains
We look for Direct pair production and Gluino mediated production



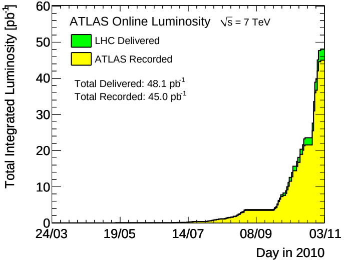


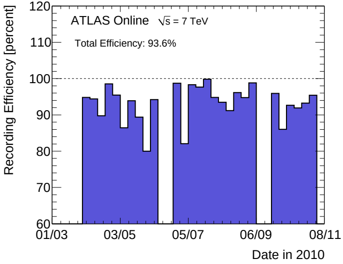
with the following decay modes:





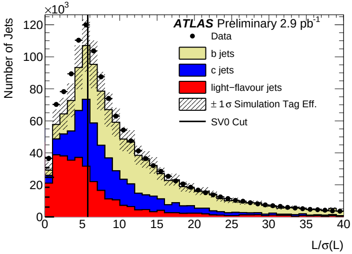
2010: Excellent LHC and ATLAS performance





Good year for ATLAS!

- 45 pb^{-1} recorded
- Good quality data-taking efficiency >90%
- Good *b*-jet identification using $L/\sigma(L)$ (SV0)



Search Strategies

- R-Parity conservation ⇒ the Lightest Supersymmetric Particle (LSP) is stable.
  - Expect large Missing Transverse Energy (E_T^{miss})
- At the LHC: Strong force production dominates. Followed by cascade decays to LSP:
  - High p_T jets and (possibly) isolated high p_T leptons
- Expect heavy flavour jets:
  - Require jets identified as b-jets (b-tag)

Optimize for a process not a specific model:

Sbottom-Gluino: 0 lepton

- $\tilde{g} \rightarrow \tilde{b}b$ with 100%
- $\tilde{b} \rightarrow b\tilde{\chi}^0$ with 100%
- $m(\tilde{\chi}^0) = 60$ GeV

Stop-Gluino: 1 lepton

- $\tilde{g} \rightarrow \tilde{t}t$ with 100%
- $\tilde{t} \rightarrow b\tilde{\chi}^{\pm}$ with 100%
- $m(\tilde{\chi}^0) = 60$ GeV, $m(\tilde{\chi}^{\pm}) \approx 2m(\tilde{\chi}^0)$

Selection Cuts: 0 lepton

Effective Mass

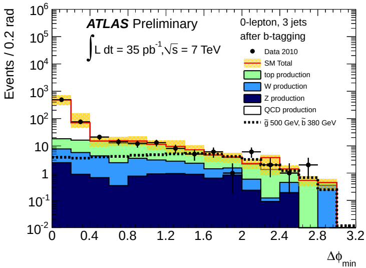
Effective Mass $M_{Eff} = E^T_{Miss} + \sum_{i=1}^{4} p_T(\text{jet}_i)$

Selection cuts: 0 lepton ($p_T > 20$ GeV)

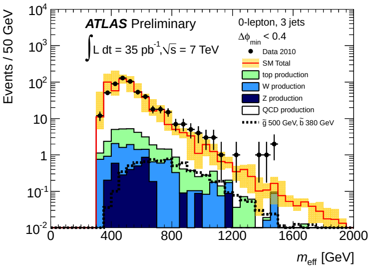
- MET + jet trigger fully efficient:
  - 3 jets with $p_T > 120, 30, 30$ GeV, within $|\eta| < 2.5$
  - $E^T_{Miss} > 100$ GeV
- QCD Rejection:
  - $E^T_{Miss}/M_{Eff} > 0.2$
  - $\Delta\phi_{\text{min}}(E^T_{Miss}, \text{jets 1-3}) > 0.4$ rad
- Enhance SUSY signal:
  - ≥ 1 b-jet (SV0>5.72, $p_T > 30$ GeV)
  - $M_{Eff} > 600$ GeV

Background Estimation: 0 lepton

Top & Vector Boson + jets: Estimated using Monte Carlo
For QCD: partially data-driven.



$\Delta\phi_{\text{min}} < 0.4$ control region.



M_{Eff} in $\Delta\Phi < 0.4$ control region

QCD estimate for $M_{eff} > M_{eff}(\text{Min})$ is then given by:

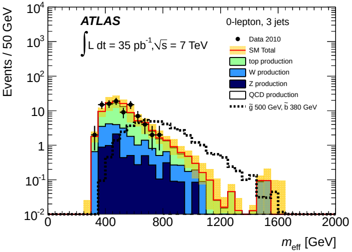
$$N^{SR}_{QCD} = (N^{CR}_{DATA} - N^{CR}_{nonQCD,MC}) \frac{N^{\Delta\phi_{\text{min}}>0.4}_{QCD,MC}}{N^{CR}_{QCD,MC}} \int_{M_{eff}(\text{Min})}^{\infty} f_{QCD}(M_{eff})\,dM_{eff}$$

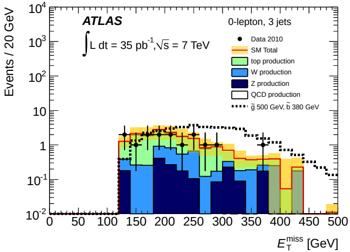
Results: 0 lepton

Dominant systematics on background estimates include JES (25% on SM prediction), b-tagging (12% for top and 25% for W/Z+jets), theoretical uncertainties on top (20%) and W/Z+jets (25%)

Good agreement between data and SM expectation.

Selection	Expected events	Observed Events
$E_T^{miss} > 100$ GeV	4800 ± 1600	5834
$E_T^{miss}/m_{eff} > 0.2$	2800 ± 900	3221
b-tag	620 ± 200	656
$\Delta\phi_{min} > 0.4$	90 ± 30	91
$m_{eff} > 600$ GeV	20 ± 7	15





Interpretation of 0 lepton results

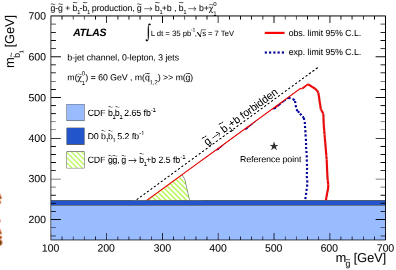
95 % C.L. UL on Cross Section × Acceptance × Efficiency

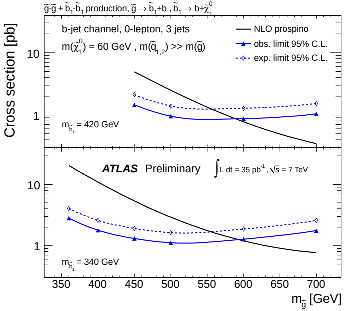
Exclude: N(events) > 10.5, $\sigma \times$ Acc $\times$ Eff > 0.32 pb

In phenomenological MSSM:

- $\tilde{g} \rightarrow \tilde{b}b$ with 100%
- $\tilde{b} \rightarrow b\tilde{\chi}^0$ with 100%
- $m(\tilde{\chi}^0) = 60$ GeV

$m(\tilde{g}) < 590$ GeV excluded for $m(\tilde{b}_1) < 500$ GeV





Selection Cuts: 1 lepton

Effective Mass

$M_{Eff} = E^T_{Miss} + \sum_{i=1}^{4} p_T(\text{jet}_i) + p_T(\text{lepton})$

Transverse Mass

$M_T = \sqrt{2 \cdot p_T(l) \cdot E_T^{Miss} \cdot (1 - \cos(\Delta\phi(l, E_T^{Miss})))}$

Selection Cuts: 1 lepton (e or μ with $p_T > 20$ GeV)

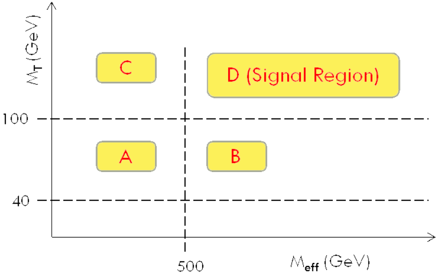
- Lepton trigger (fully efficient for $p_T > 20$ GeV)
- 2 jets, p_T >60,30 GeV within $|\eta| < 2.5$
- $E^T_{Miss} > 80$ GeV
- $M_T > 100$ GeV
- ≥ 1 b-jet (SV0>5.72, $p_T > 30$ GeV)
- $M_{Eff} > 500$ GeV

Background Estimation: 1 lepton

The background estimation is data driven.

- The QCD is measured using a matrix-method and found to be negligible.
- The top and vector boson + jets are measured using the ABCD method:

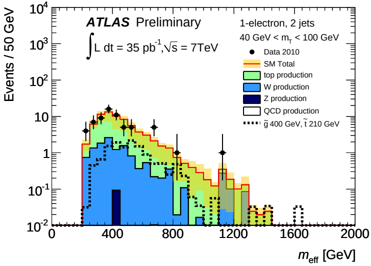
We exploit the low correlation between M_T and M_{Eff}:

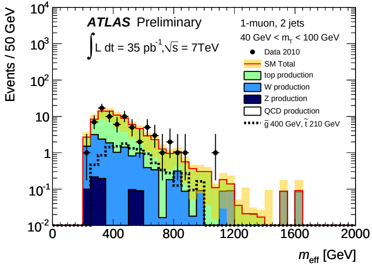


The number of events in the Signal Region is then $N_D = N_C/N_A \times N_B$

Background Estimation: 1 lepton

Cross check with MC gives good agreement.



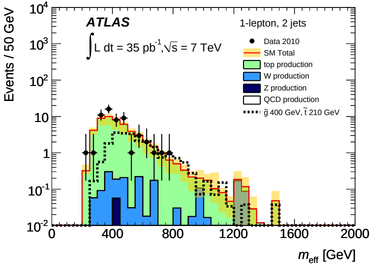


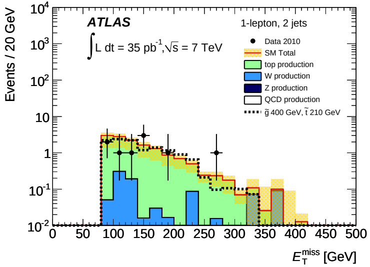
Region	Data	Monte Carlo
A: $40 < m_T < 100$ GeV and $m_{eff} < 500$ GeV	103	105.1 ± 1.5
B: $m_T > 100$ GeV and $m_{eff} < 500$ GeV	46	35.9 ± 0.5
C: $40 < m_T < 100$ GeV and $m_{eff} > 500$ GeV	33	40.1 ± 0.8
D: $m_T > 100$ GeV and $m_{eff} > 500$ GeV	9	13.5 ± 0.4
Estimation	14.7 ± 3.7	13.7 ± 0.4
Ratio	(164 ± 41) %	(101.2 ± 2.9)%

Results: 1 lepton

Uncertainties (25%) dominated by statistics in the control regions.
Agreement between data and SM expectation.

Selection	Expected events (MC)	Expected events (m_T)	Measured Events
$m_T > 100$	50 ± 20	–	55
$m_{eff} > 500$ GeV	13.5 ± 4.1	14.7 ± 3.7	9





Interpretation of 1 lepton results

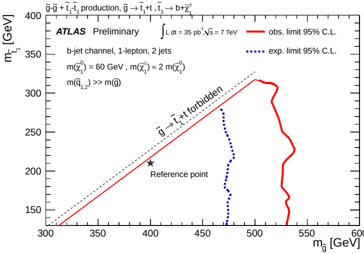
95 % C.L. UL on Cross Section × Acceptance × Efficiency

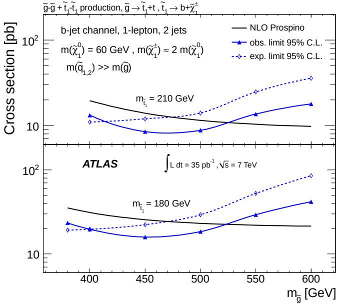
Exclude: N(events) > 4.7, $\sigma \times$ Acc $\times$ eff > 0.13 pb

Also within phenomenological MSSM:

- $\tilde{g} \rightarrow \tilde{t}t$ with 100%
- $\tilde{t} \rightarrow b\tilde{\chi}^{\pm}$ with 100%
- $m(\tilde{\chi}^0) = 60$ GeV, $m(\tilde{\chi}^{\pm}) \approx 2m(\tilde{\chi}^0)$

$m(\tilde{g}) < 520$ GeV excluded for $m(\tilde{t}_1) < 300$ GeV

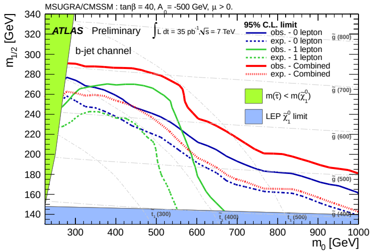




Interpretations within specific models

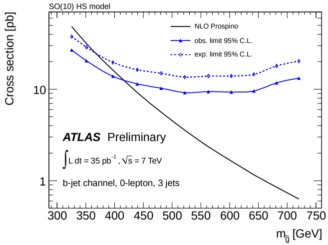
Look at mSUGRA/CMSSM:

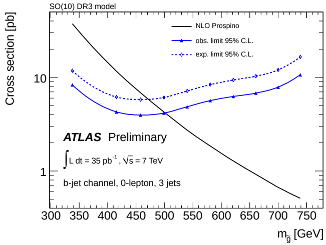
- High $\tan\beta$, low $A_0 \Rightarrow$ lower $m(\tilde{t}_1)$, $m(\tilde{b}_1)$
- $A_0 = -500$ GeV, 0 GeV (backup)
- Combine 0, 1-lepton analyses



$m(\tilde{g}) < 500$ GeV excluded for 250 GeV $< m_0 <$ 1 TeV.

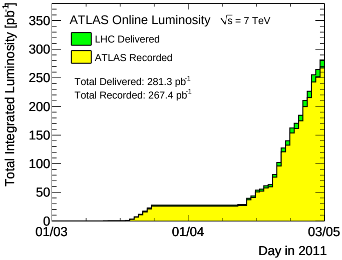
SO(10) models where $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_2^0$ (HS) and $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (DR3):





Conclusions and outlook

This is all documented in ArXiV:1103.4344 (submitted to PLB)



- Took a good bite out of the SUSY parameter space
- Already loads of data this year (267 pb^{-1} already!)
- 2011 analyses will be performed with improved detector systematics
- Now optimizing the analyses for sbottom/stop pair production, accessible with increased amount of data

BACKUP SLIDES

Backup: Object Definitions

Vertex:At least 1 vertex with $N_{tracks} > 4$

Missing Transverse Energy: from Objects & clusters

Jets

- Anti-kT, R $= 0.4$
- $p_T > 20$GeV, $|\eta| < 2.5$
- Veto Calorimeter noise and cosmics

Electrons

- $p_T > 20$GeV, $|\eta| < 2.47$
- Veto electrons in the crack region $1.37 < |\eta| < 1.52$

b-Jets

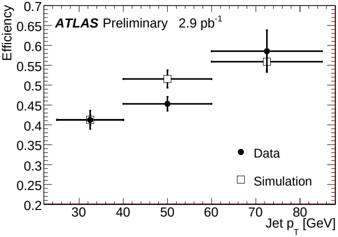
- Jets with $p_T > 30\,GeV$
- SV0 weight > 5.72

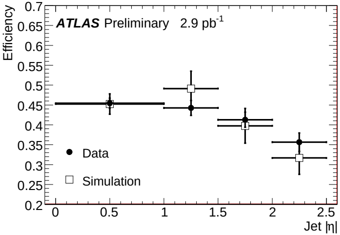
Muon

- $p_T > 20$GeV, $|\eta| < 2.4$
- Total track p_T within $\Delta R < 0.2$ less than 1.8 GeV

Backup: *b*-jets (SV0)

- SV0 is a lifetime-based tagging algorithm which relies on the explicit reconstruction of secondary vertices within jets.
- Reconstruct a vertex from all tracks associated to the jet which are displaced from the primary vertex
- A jet is considered a *b*-jet if the signed decay length significance, $L/\sigma(L)$, of the reconstructed secondary vertex, computed with respect to the primary vertex, is above a certain value.





Backup: 0-lepton background composition

Background composition for 1 pb^{-1}

Cut	$t\bar{t}$	$W+$ jets	Wbb	$Z+$ jets	Zbb	single top
$E_T^{miss} > 100$ GeV	3.55 ± 0.02	9.29 ± 0.15	0.1 ± 0.01	4.66 ± 0.14	0.054 ± 0.002	0.30 ± 0.02
$E_T^{miss}/m_{eff} > 0.2$	3.05 ± 0.02	8.36 ± 0.14	0.09 ± 0.01	4.28 ± 0.14	0.047 ± 0.001	0.26 ± 0.02
1 b-tagged jet	2.15 ± 0.02	0.69 ± 0.04	0.06 ± 0.01	0.28 ± 0.03	0.022 ± 0.001	0.16 ± 0.01
$\Delta\phi_{min} > 0.4$	1.60 ± 0.02	0.42 ± 0.03	0.05 ± 0.01	0.19 ± 0.03	0.016 ± 0.001	0.11 ± 0.01
$m_{eff} > 600$ GeV	0.33 ± 0.01	0.11 ± 0.02	0.006 ± 0.002	0.05 ± 0.01	0.0031 ± 0.0003	0.02 ± 0.01

with associated systematic errors:

Process	MC stat	JES	b-tagging	Lum.	Theor.	Pileup	other (lepton, trigger)	Total
W	$\pm 15\%$	$\pm 24\%$	$\pm 24\%$	$\pm 11\%$	$\pm 27\%$	$\pm 5\%$	$\pm 3.5\%$	$\pm 43\%$
Z	$\pm 27\%$	$\pm 20\%$	$\pm 25\%$	$\pm 11\%$	$\pm 27\%$	$\pm 5\%$	$\pm 3.5\%$	$\pm 45\%$
Top	$\pm 2.5\%$	$^{+30\%}_{-23\%}$	$^{+12\%}_{-15\%}$	$\pm 11\%$	$^{+20\%}_{-27\%}$	$\pm 5\%$	$\pm 3.5\%$	$\pm 40\%$

Backup: 1-lepton QCD Background estimation

- Define loose and tight selections where tight = loose + additional criteria
- Numbers of observed loose and tight candidates are:

$$N(loose) = N(loose, real) + N(loose, fake) \quad (1)$$

$$N(tight) = r \times N(loose, real) + f \times N(loose, fake) \quad (2)$$

where r and f are the probabilities for real and fake candidates that pass the loose criteria to also pass the tight ones

- r and f can be measured from control samples enriched with real/fake objects
- Determine $N(tight)$ from $N(loose)$, r and f:

$$N(tight, fake) = \frac{f}{r - f}(r \times N(loose, real) - N(tight)) \quad (3)$$

Backup: Signal Systematics

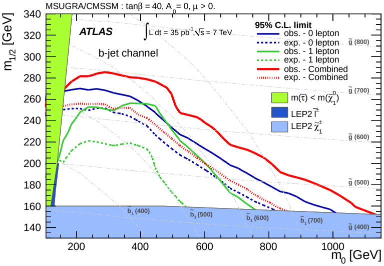
Detector systematic uncertainties depend on the signal:

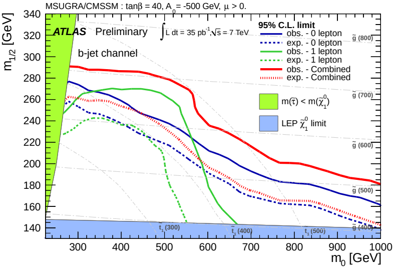
- Between 25% and 10% as gluino/squark masses increase from 300 GeV to 1 TeV
- Low mass: dominated by JES, high mass: dominated by b-tagging

Theoretical Uncertainties:

- Renormalization/factorization scale: 16% for $\tilde{g}\tilde{g}$ production and 30% (27%) for $\tilde{b}\tilde{b}(\tilde{t}\tilde{t})$
- PDF Uncertainties
  - $\tilde{g}\tilde{g}$: 11% to 25%
  - $\tilde{b}\tilde{b}, \tilde{t}\tilde{t}$: 7% to 16%

Backup: mSUGRA exclusion with $A_0 = 0$ GeV





Exclusion limits in mSUGRA with $A_0 = 0$ GeV (left) and $A_0 = -500$ GeV (right).

Backup: SO(10)

SO(10) SUSY is determined by the parameters:

- m_{16}: common GUT scale mass of matter scalars
- m_{10} GUT scale mass of Higgs scalars
- M_D^2: parametrizes potential splittings in GUT scale Higgs soft terms
- m_{12}: common GUT scale gaugino mass
- A_0: unified GUT scale soft SUSY breaking trilinear term
- $\tan\beta$: weak scale ratio of higgs field
- sign(μ): μ is the superpotential Higgs bilinear term

The particle mass spectrum is characterised by:

- low gluino masses (300-600 GeV)
- low chargino masses (100-180 GeV)
- low neutralinos masses (50-90 GeV)
- all scalar particles have masses beyond the TeV scale.

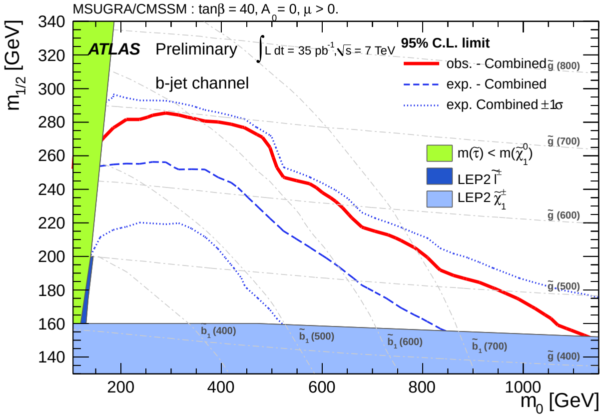
Backup: Exclusion Technique

- The tool used to calculate the limits uses a profile-likelihood technique.

$$L(\mathbf{n}|\mu, \mathbf{b}, \boldsymbol{\theta}) = P(n_S|\lambda_S(\mu, \mathbf{b}, \boldsymbol{\theta})) \times P_{Syst}(\boldsymbol{\theta}^{\mathbf{0}}, \boldsymbol{\theta})$$

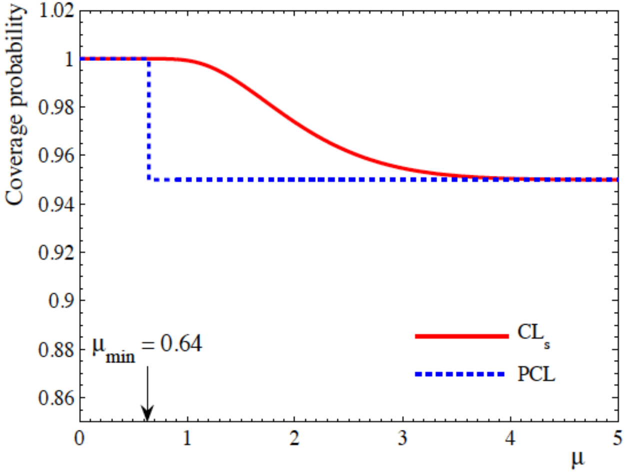
  where, for the second term:
  - JES (Signal and Background correlated)
  - b-tagging (Signal and Background correlated)
  - Luminosity (Signal and Background correlated)
  - Theoretical Signal uncertainties (PDF, Scale)
  - Other Background uncertainties

Backup: Exclusion Technique

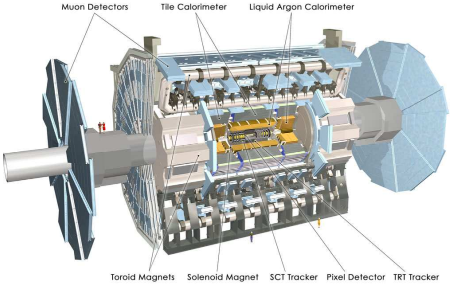


Observed and expected 95% C.L. exclusion limits as obtained from the combined zero- and one-lepton analyses on an mSUGRA scenario with $\tan\beta=40$, $A_0=0$, $\mu > 0$. The light-blue dashed lines show the $\pm1\sigma$ lines.

Backup: CLs vis-a-vis PCL



Backup: The ATLAS Experiment



- Inner detector: charged particle tracks and vertices, 2T solenoidal magnetic field
- Liquid argon and Tile calorimeters: electromagnetic and hadronic showers
- Muon spectrometer: muon tracks, toroidal magnetic field