Searches for 3rd generation SUSY in ATLAS

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On behalf of the ATLAS collaboration

Rencontres de Moriond EW 2012

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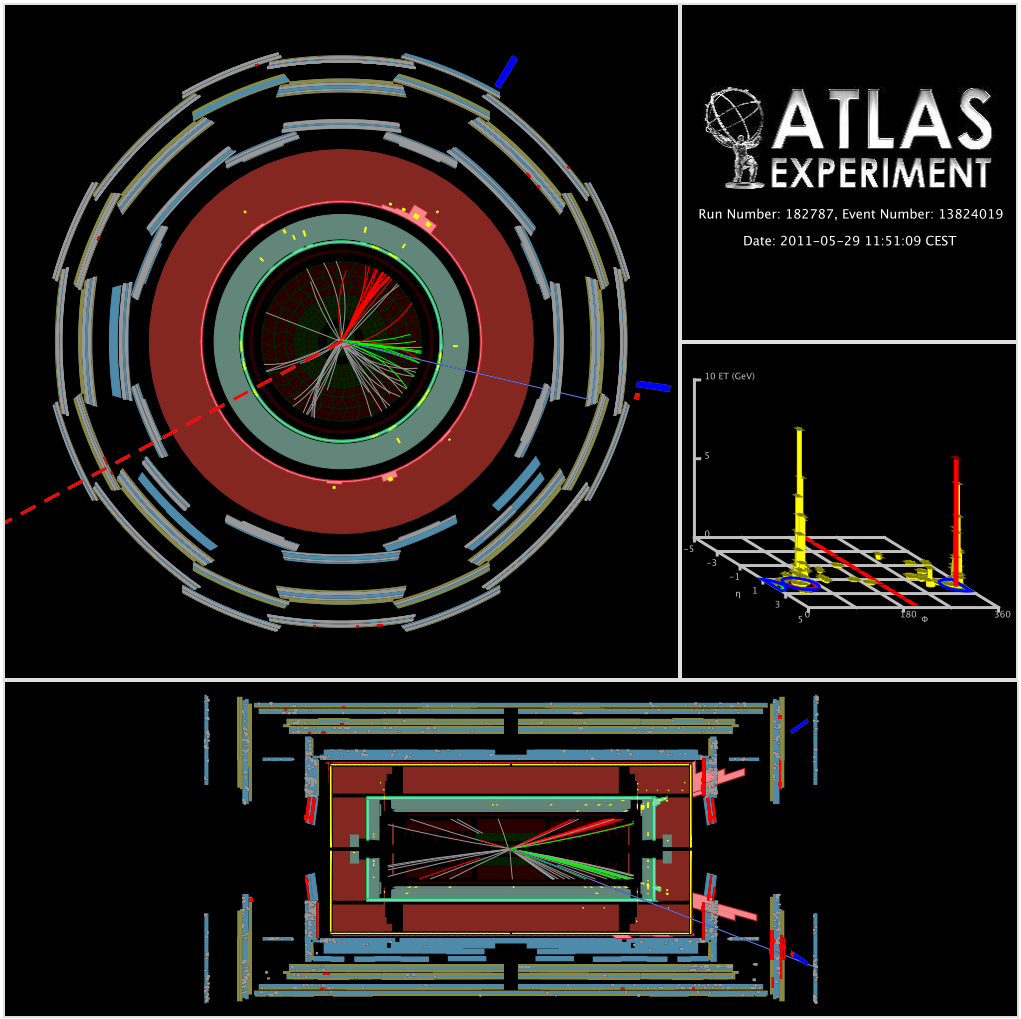
La Thuile, Italy



$\tilde{b}_1\tilde{b}_1$ event candidate : 2 b-jets + $\not{E}_T$

Introduction

■ Motivation :

I Supersymmetry can solve "naturally" the hierarchy problem provided third generation squarks are light

II Large mixing of $(\tilde{f}_L, \tilde{f}_R)$ in the third generation

$\Longrightarrow \tilde{t}_1$ and $\tilde{b}_1$ lighter than other squarks

$\Longrightarrow \tilde{\tau}_1$ lighter than other sleptons

■ Strategy for $\tilde{t}_1$ and $\tilde{b}_1$ searches :

• **If the gluino is light enough :**

▶ Look at gluino mediated $\tilde{t}_1$ / $\tilde{b}_1$ production

$\Longrightarrow$ Very rich final states :

◦ gluino-mediated sbottom pair production :
$\rightarrow$ 4 b-jets + large $\not{E}_T$

◦ gluino-mediated stop pair production :
$\rightarrow$ many jets, b-jets, leptons and large $\not{E}_T$

• **If only $\tilde{t}_1$ and $\tilde{b}_1$ are light :**

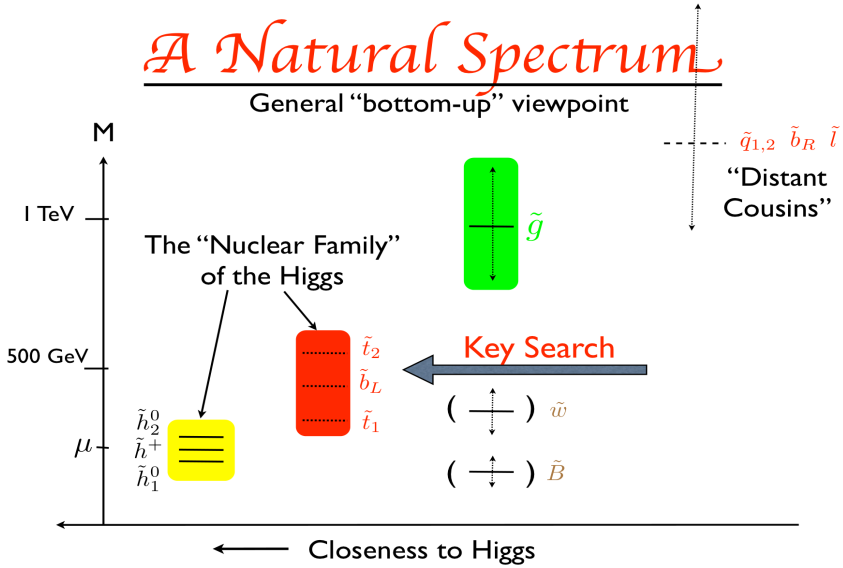
▶ Look at direct $\tilde{t}_1$ and $\tilde{b}_1$ pair production :

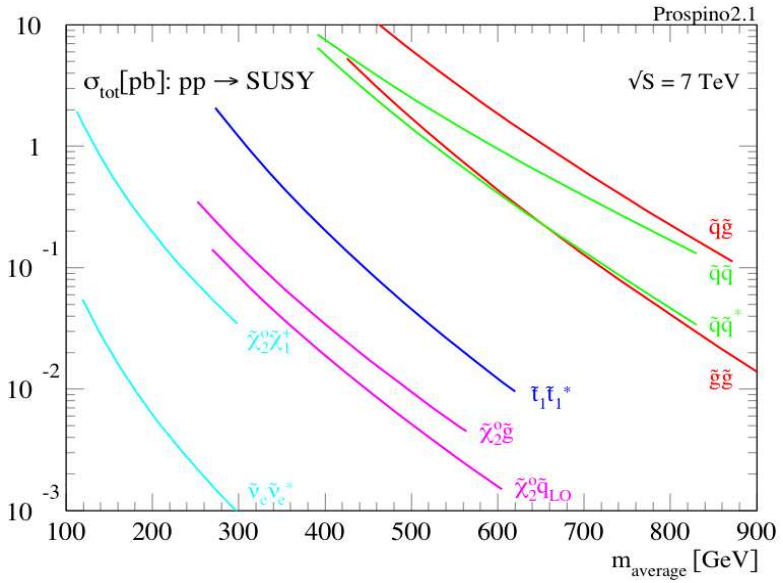
$\Longrightarrow$ final states similar to SM processes :

◦ Direct sbottom pair production : $\rightarrow$ 2 b-jets + $\not{E}_T$

◦ Direct stop pair production : $\rightarrow$ ex : $t\bar{t}$ + $\not{E}_T$

From Lawrence Hall, October 2011





General approach in ATLAS SUSY searches

All analyses shown here are "cut and count" analyses :

I Definition of the signal regions :

- Choose variables which can discriminate between signal and background

$\rightarrow$ jets, b-jets, leptons, $\not{E}_T$, effective mass ($m_{eff} = \not{E}_T + \sum_{jets} p_T + \sum_{leptons} p_T$)

- Cut sufficiently hard to reach the plateau of the trigger and enhance S/B

$\rightarrow$ Optimisation driven by L^{int} and the existence of methods to estimate the backgrounds

II Estimate the background :

- QCD multijets : estimated via data-driven methods
- Dominant SM processes : estimated with semi data-driven methods based on transfer factors from control regions to signal regions
- Smaller SM processes : extracted from Monte Carlo simulations

III Estimate the systematic uncertainties

- Detector related uncertainties : jet energy scale/resolution, b-tagging efficiency, lepton ID...
- Theoretical uncertainty : MC generator, ISR/FSR, PDF, factorisation/renormalisation scales ...

IV Interpretation of the results

If no excess is observed in data, derive exclusion limits at 95% C.L. using CL_s in a model independent way or in the context of different susy scenarios

Estimation of the QCD multijet background : data-driven

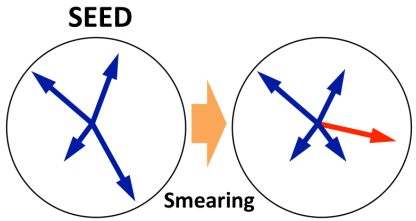
■ **Analyses with 0-lepton final states :** Jet Smearing Method

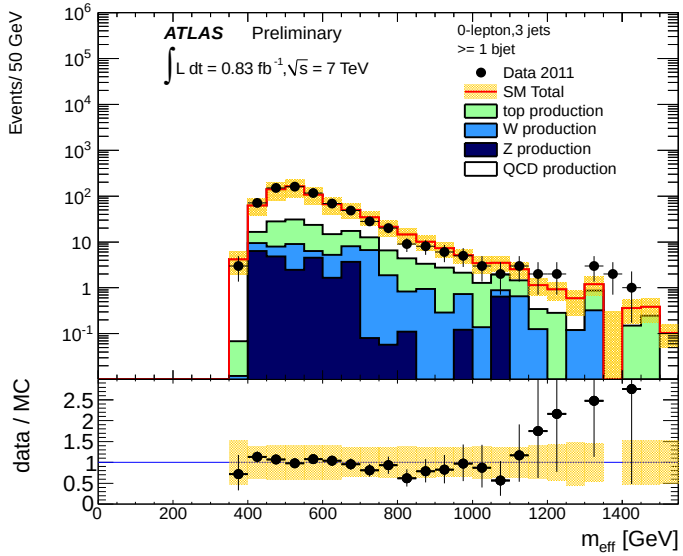
► Estimate contribution from events with fake $\not{E}_T$ due to jet energy mismeasurement

I Build the jet response function R (p_T^{reco}/p_T^{true}) using dijet balance (Gaussian core) and Mercedes events (tails)

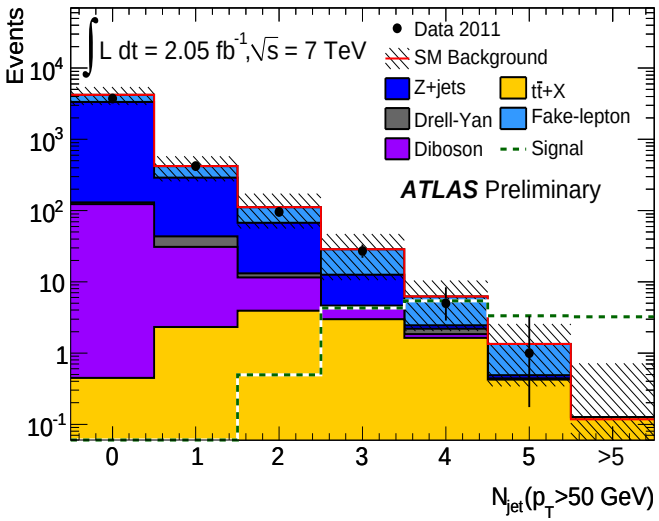
II Use a multijet control samples with low $\not{E}_T$

III Smear each jet p_T with R to generate QCD pseudo-events :





IV Normalise the shape in a multijets enhanced region with $\Delta\phi_{min}(\not{E}_T, jet) < 0.4$



■ **Analyses with 1/2 lepton final states :** Matrix Method

► Estimate contribution from events with non-prompt leptons arising from b/c decay, γ conversion and jet misID

I Define 2 data samples with $\neq$ lepton criteria selection : tight (standard selection) and loose (relaxed criteria)

II Measure in data the "loose $\rightarrow$ tight" ε for real/fake leptons

III Count the number of events in the 2 samples to extract the multijet background

Estimation of the dominant backgrounds : semi data-driven

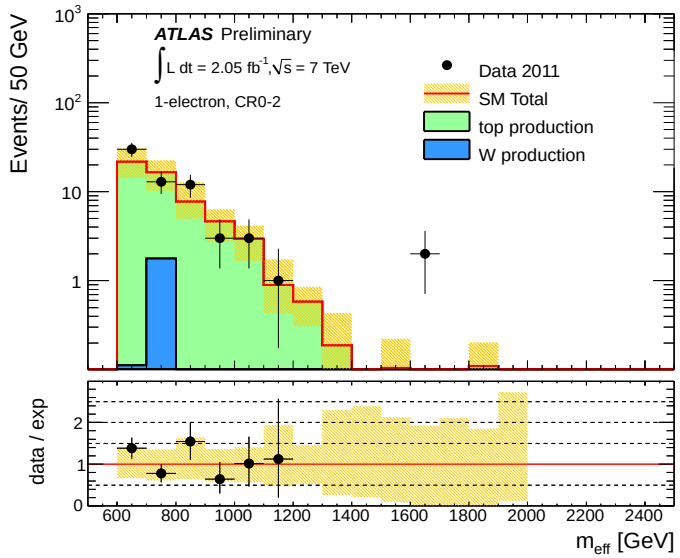
■ Most analyses estimate the dominant top and W/Z backgrounds using a semi-data method based on Transfer Factors from background enhanced control regions (CR) to the signal regions (SR) :

$$N_{\mathrm{SR}}^{bkg,est} = \frac{N_{\mathrm{SR}}^{\mathrm{bkg,MC}}}{N_{\mathrm{CR}}^{\mathrm{bkk,MC}}}(N_{\mathrm{CR}}^{\mathrm{data}} - N_{\mathrm{CR}}^{\mathrm{other,MC}}) = T_f^{bkg}(CR \rightarrow SR)(N_{\mathrm{CR}}^{\mathrm{data}} - N_{\mathrm{CR}}^{\mathrm{other,MC}})$$

$\Longrightarrow$ Correlated systematic uncertainties between the control and signal regions largely cancel out in the transfer factor.

Example : $t\bar{t}$ estimate in the gluino-mediated sbottom analysis ($0\ell + \not{E}_T + b$-jets) :

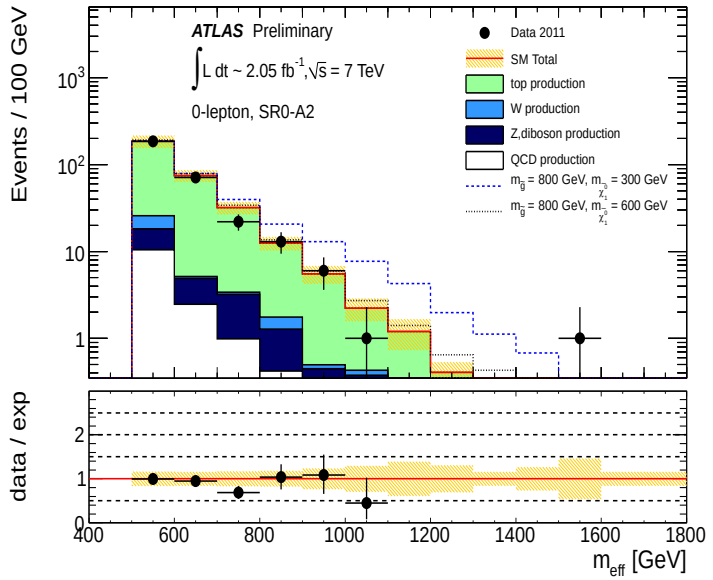
$t\bar{t}$ CR : $1\ell + \not{E}_T + 2\ b$-jets



$T_f^{t\bar{t}}[CR(1\ell) \rightarrow SR(0\ell)]$

$T_f = 4$

SR : $0\ell + \not{E}_T + 2\ b$-jets



Search for gluino and squark mediated stau production

$1\tau + \not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-005

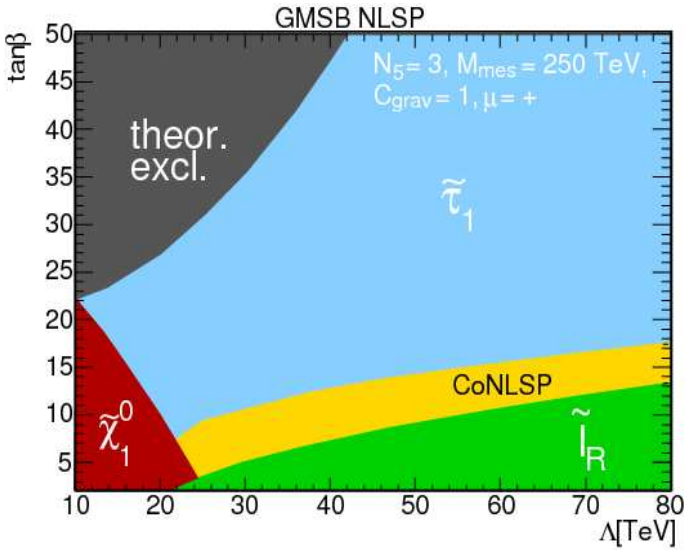
$2\tau + \not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-002

Gluino and squark mediated $\tilde{\tau}_1$ production : the 2 analyses

■ Search for $\tilde{\tau}_1$ production in the context of Gauge Mediated Susy Breaking (GMSB)

Large mixing of gauge eigenstates ($\tilde{\tau}_R$,$\tilde{\tau}_L$) leads to light $\tilde{\tau}_1$

$\rightarrow \tilde{\tau}_1$ often NLSP in GMSB

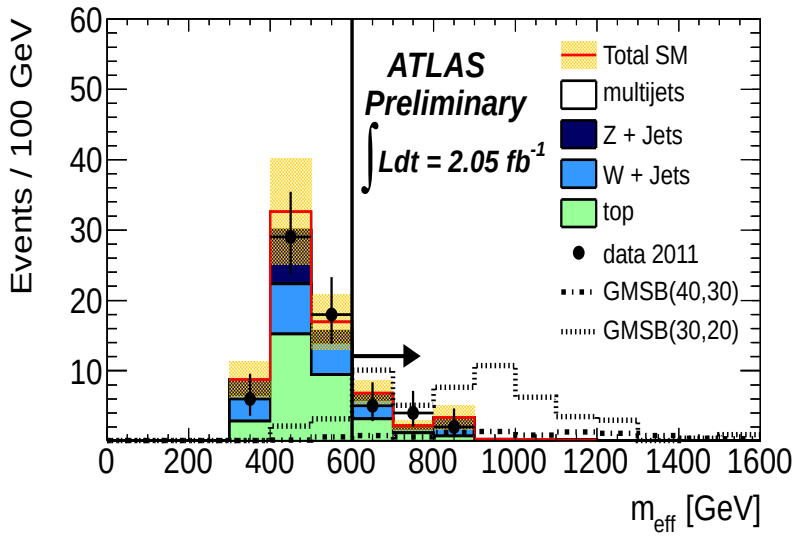


■ 2 analyses targeting $\tilde{\tau}_1$ production :

- jet+$\not{E}_T$ trigger : $\not{E}_T$, $p_T(j_1) > 130$ GeV
- $\geqslant 2$ jets with $p_T(j_2) > 30$ GeV

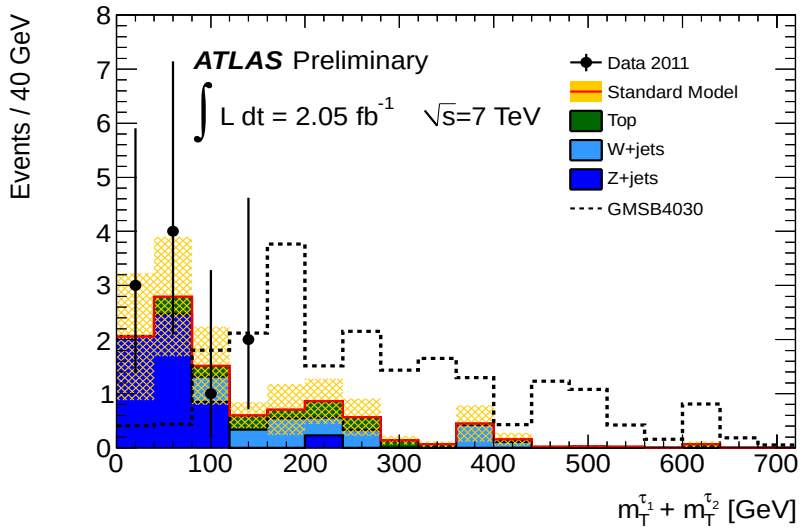
$\geqslant 1$ tight hadronic τ ($p_T > 20$ GeV)

- $m_T(\tau) > 110$ GeV, $m_{eff} > 600$ GeV



$\geqslant 2$ loose hadronic τ ($p_T > 20$ GeV)

- $m_{eff} > 700$ GeV ; $m_T(\tau_1) + m_T(\tau_2) > 80$ GeV



Gluino and squark mediated $\tilde{\tau}_1$ production : interpretation

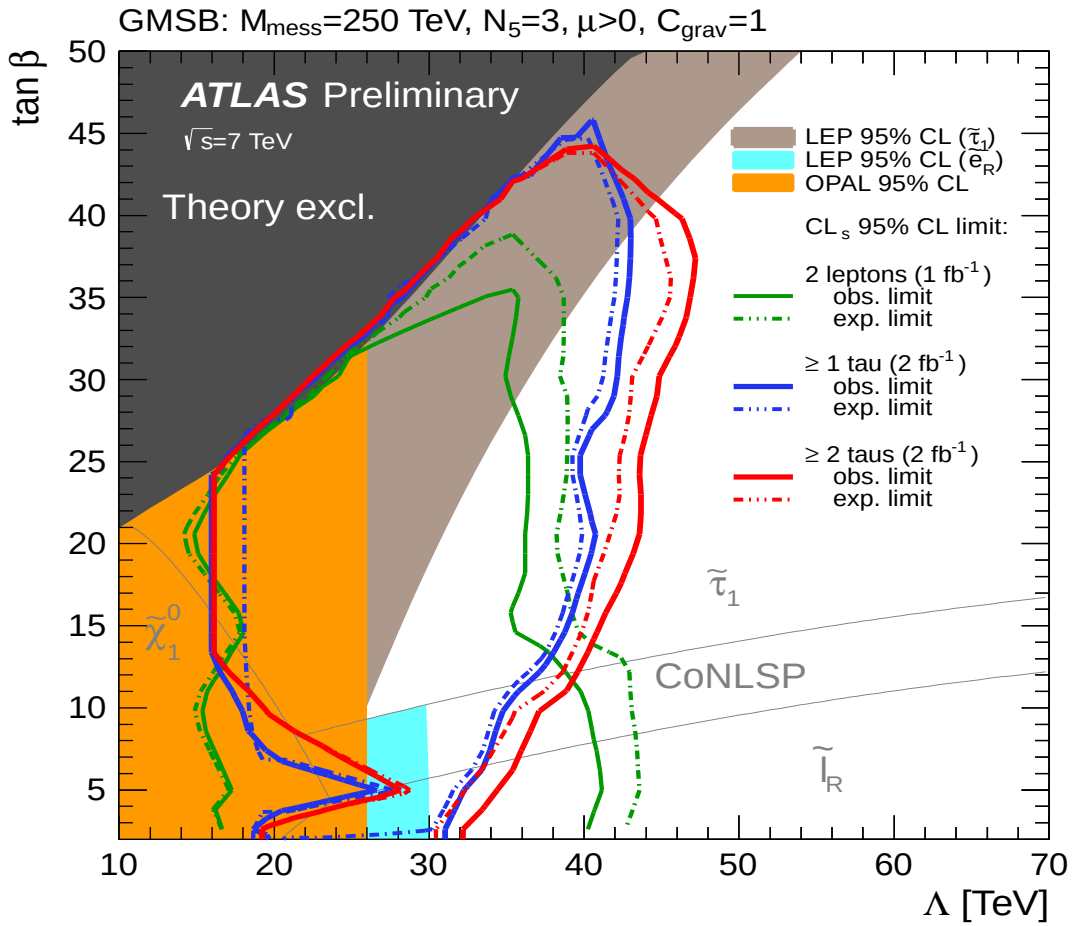
- Results are interpreted in the context of GMSB in the (Λ, tan β) plane

Hypotheses :

- $M_{mess} = 250$ TeV, $N_5 = 3$, $\mu > 0$, $C_{grav} = 1$
- Production of squarks and gluinos which decay directly or through cascade to NLSP with subsequent decay to LSP
- LSP = Gravitino $\tilde{G}$ ($\mathcal{O} \backsim$ keV)
- NLSP = $\tilde{\tau}_1$,$\tilde{\ell}_R$, $\tilde{\chi}_1^0$, $\tilde{\nu}$

$\tilde{\tau}_1$ NLSP for most of parameter space at large tan β

Results from the ATLAS dilepton OS (e,μ) with 1 fb^{-1} also shown (ATLAS-CONF-2011-156)



- 1 τ analysis : Exclude $\Lambda < 40$ TeV for tan $\beta > 15$
- 2 τ analysis : best exclusion is set for $\Lambda = 47$ TeV for tan $\beta = 37$

Search for direct sbottom pair production

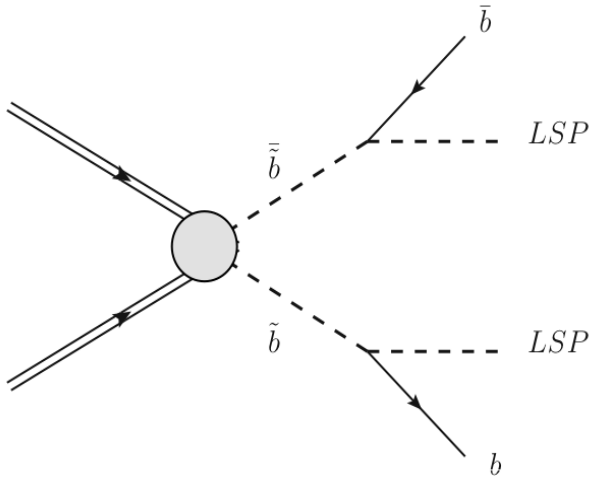
0ℓ + b-jets + $\not{E}_T$ analysis with 2 fb^{-1} : arXiv :1112.3832, accepted by PRL

Direct sbottom pair production : description of the analysis

■ Search for direct sbottom pair production with $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$

▶ Event Selection : Exactly 2 b-jets + $\not{E}_T$

Cuts at 130 GeV on $\not{E}_T$ and $p_T(j_1)$ driven by the jet+$\not{E}_T$ trigger



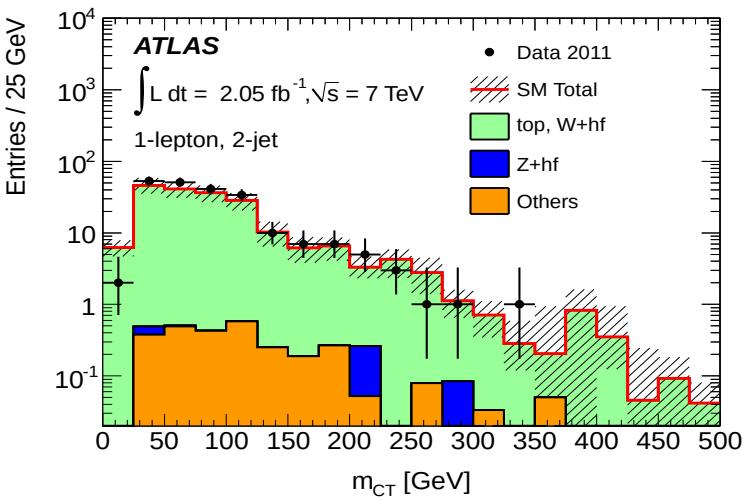
■ Signal regions defined with the boosted-corrected contransverse mass m_{CT} (JHEP 0804, 034 (2008) ; JHEP 1003, 030 (2010)) :

$$m_{CT}^2(b_1, b_2) = [E_T(b_1) + E_T(b_2)]^2 - [\mathbf{p_T}(b_1) - \mathbf{p_T}(b_2)]$$

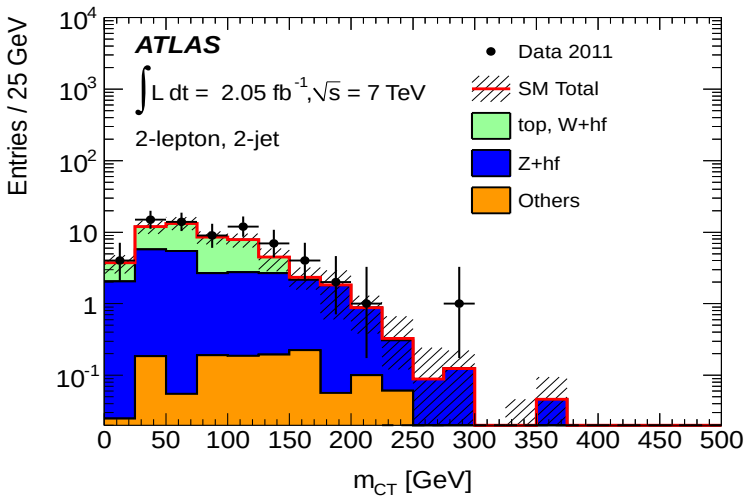
- For $\tilde{b}_1\tilde{b}_1$ events : $m_{CT}(b, b)$ has an end-point defined by : $\frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)}$
- For $t\bar{t}$ events : $m_{CT}(b, b)$ has an end-point around 135 GeV

■ Dominant backgrounds ($t\bar{t}$, W/Z+HF) estimated using transfer factors in 2 control regions :

$t\bar{t}$, W+HF CR : 1ℓ + $\not{E}_T$ + 2 b-jets



Z+HF CR : 2ℓ + $\not{E}_T$ + 2 b-jets



Direct sbottom pair production : results and interpretation

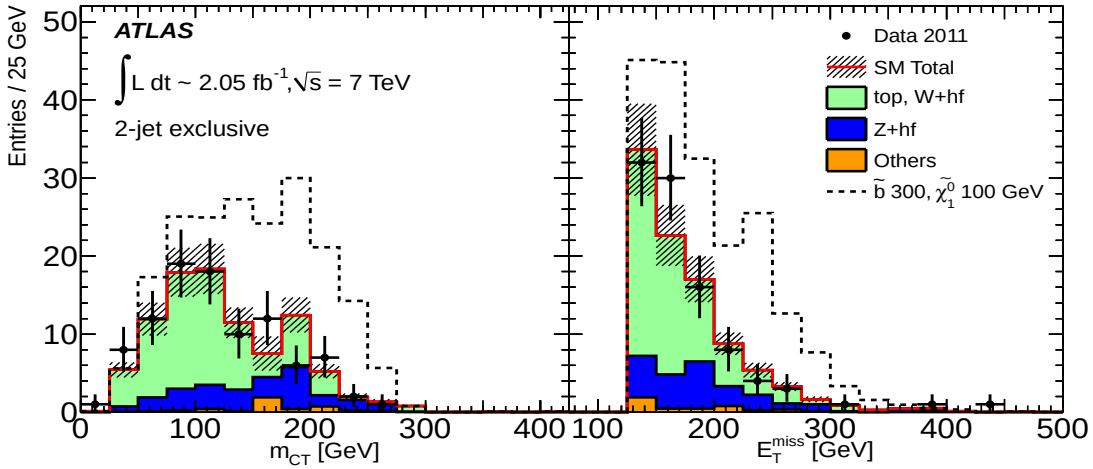
■ Good agreement between data and SM prediction in the 3 signal regions : $m_{CT} > 100, 150, 200$ GeV

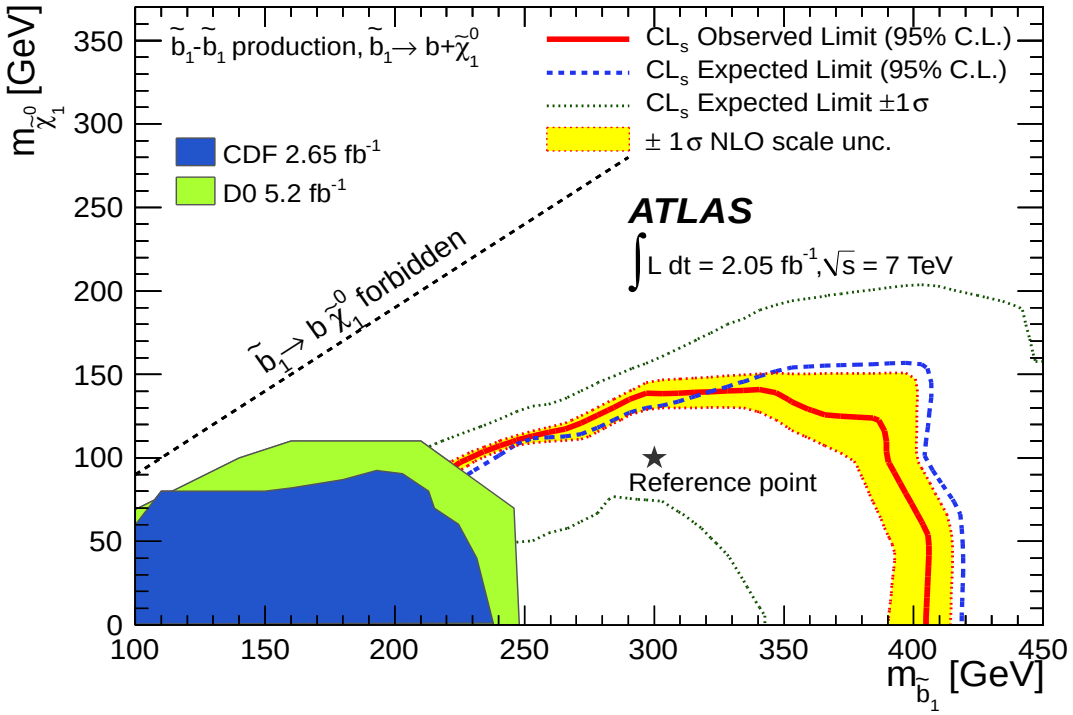
► Extract limits at 95% C.L. in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0})$ plane for a MSSM scenario with $BR[\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0] = 1$

■ For each point, the SR with the best expected sensitivity is used to extract the limits

► Exclude $m_{\tilde{b}_1} < 390$ GeV for $m_{\tilde{\chi}_1^0} = 0$ GeV

► Exclude $m_{\tilde{\chi}_1^0} < 120$ GeV for $275 < m_{\tilde{b}_1} < 350$ GeV





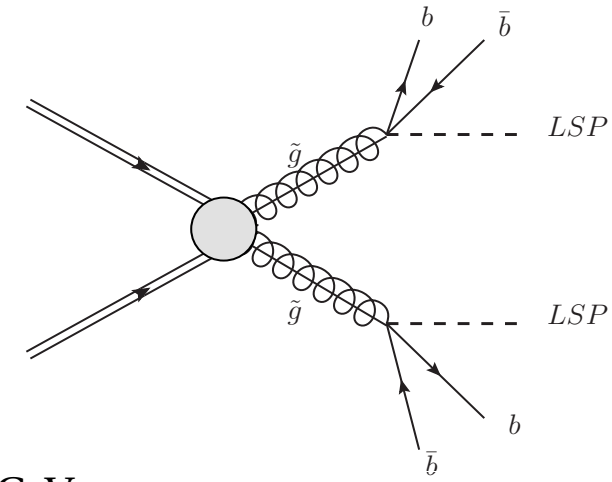
Search for gluino mediated sbottom pair production

0-ℓ + b-jets + $\not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-003

Gluino mediated sbottom pair production : description of the analysis

■ Search for gluino mediated sbottom pair production with $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$

▶ Signature : 4 b-jets + $\not{E}_T$

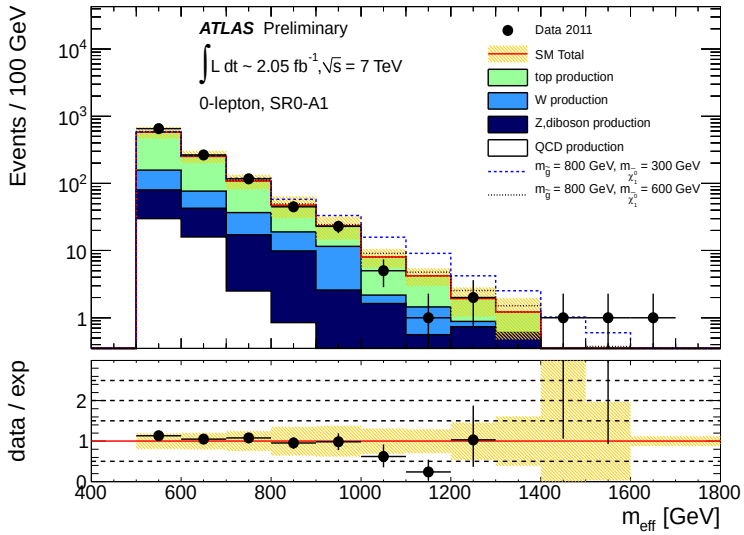


- Event selection : 0ℓ + b-jets analysis
- single jet+$\not{E}_T$ trigger : $\not{E}_T$, $p_T(j_1) > 130$ GeV
- $\geqslant 3$ jets with $p_T > 50$ GeV
- lepton veto

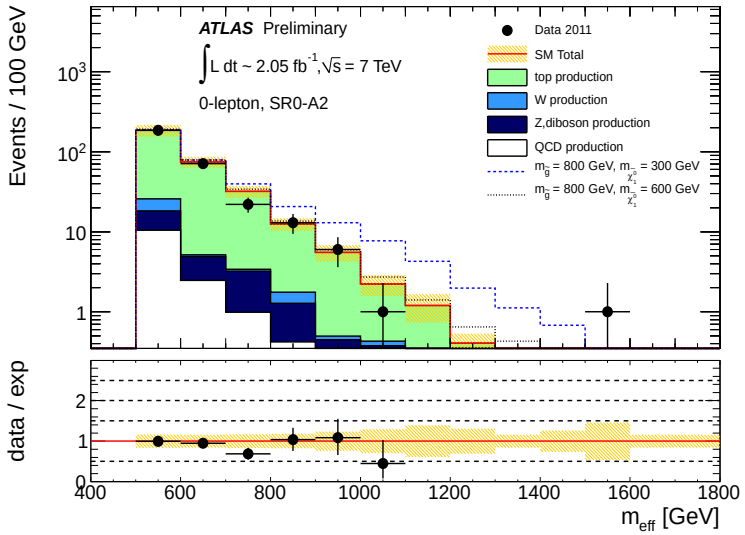
We introduce the effective mass : $m_{eff} = \not{E}_T + \sum_{i=1}^{3} p_T^{j_i}$

→ Define 6 signal regions : $\geqslant 1$ or 2 b-jets and $m_{eff} > 500, 700, 900$ GeV

m_{eff} in 1 b-jet signal regions



m_{eff} in 2 b-jet signal regions



Gluino mediated sbottom pair production : interpretation

Phenomenological MSSM model

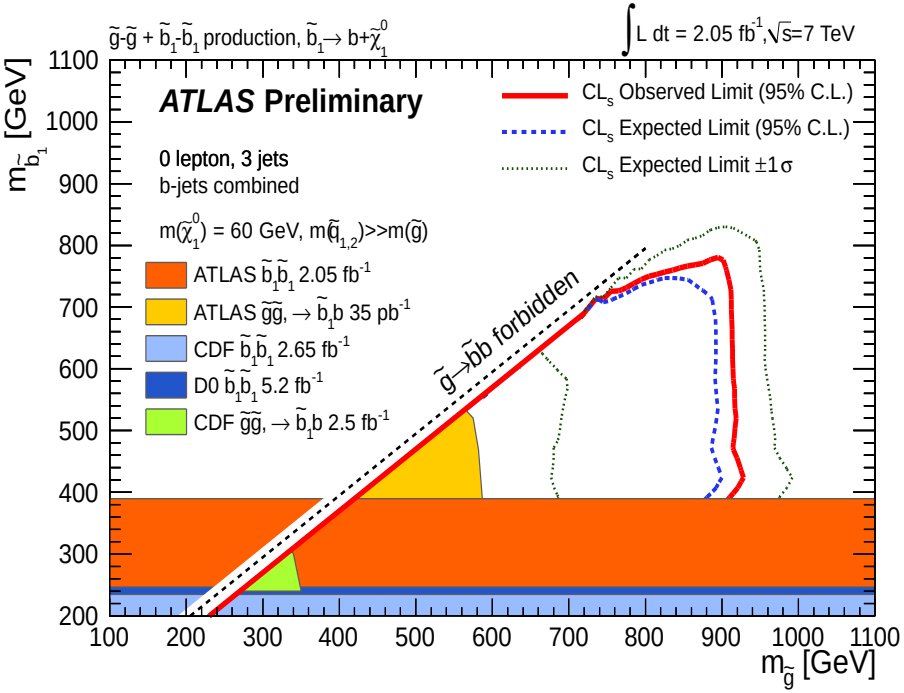
- Production : $\tilde{g}\tilde{g} + \tilde{b}_1\tilde{b}_1$
- Mass spectrum : $m_{\tilde{\chi}_1^0} < m_{\tilde{b}_1} < m_{\tilde{g}}$

$m_{\tilde{\chi}^0} = 60$ GeV, $m_{\tilde{\chi}_1^\pm} \approx 2m_{\tilde{\chi}_1^0}$

- Decays :

$\tilde{g} \to \tilde{b}_1 b, \qquad \tilde{b}_1 \to b + \tilde{\chi}_1^0$

▶ Exclude $m_{\tilde{g}} < 920$ GeV for $m_{\tilde{b}_1} < 800$ GeV



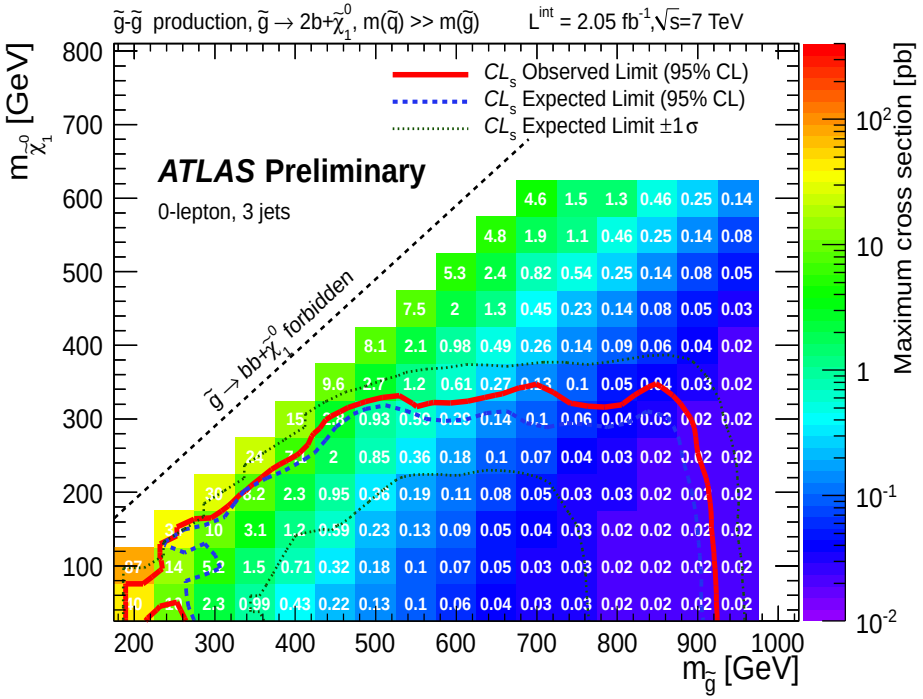
Simplified model

- Production : $\tilde{g}\tilde{g}$
- Mass spectrum : $m_{\tilde{\chi}^0} < m_{\tilde{g}} < m_{\tilde{b}_1}$
- Decays :

$\tilde{g} \to b\bar{b} + \tilde{\chi}_1^0$ via offshell sbottom decay

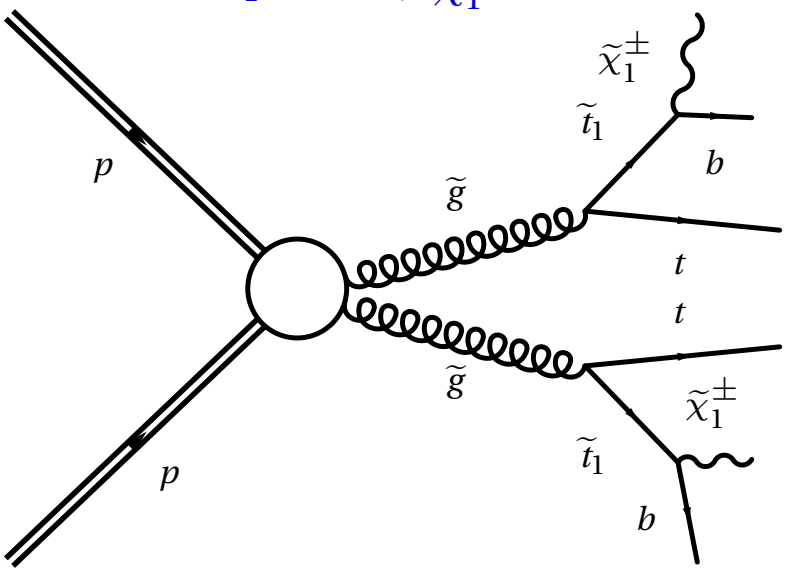
▶ Exclude $m_{\tilde{g}} < 900$ GeV for $m_{\tilde{\chi}_1^0} < 300$ GeV

▶ Extract cross section UL : $\sigma_{95}^{obs} = \frac{N_{95}^{obs}}{\mathcal{L}.\varepsilon\mathcal{A}}$

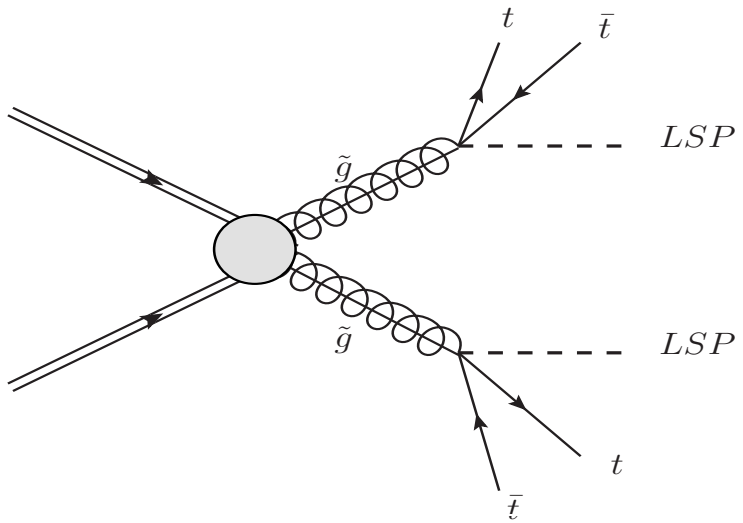


Search for gluino mediated stop pair production

$\tilde{t}_1 \to b + \tilde{\chi}_1^{\pm}$



$\tilde{t}_1 \to t + \tilde{\chi}_1^0$



1-ℓ + b-jets + $\not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-003

2-ℓ SS + $\not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-004

Gluino mediated stop pair production : description of the analyses

- Search for gluino mediated stop pair production with $\tilde{t}_1 \to t + \tilde{\chi}_1^0$ or $\tilde{t}_1 \to b + \tilde{\chi}_1^\pm$
  - ▶ Signature : many jets, including b-jets, leptons, $\not{E}_T$
- 2 different analyses interpreted in this context :

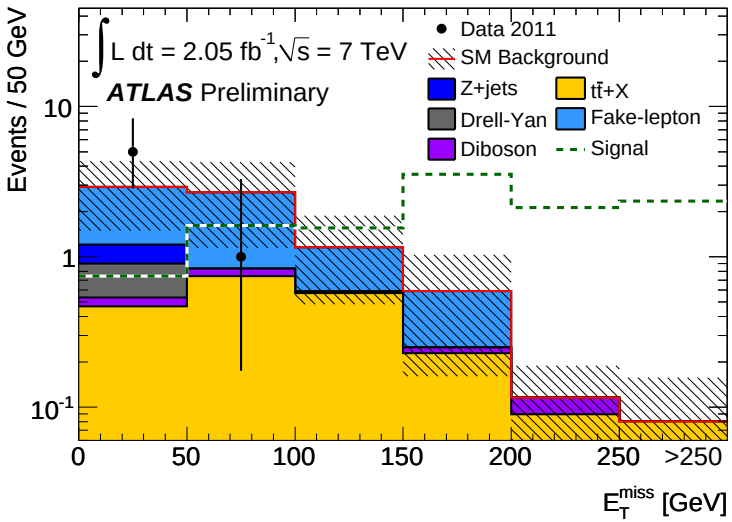
2 same-sign leptons

- $\geqslant$ 2 leptons (e,μ) with $p_T > 20$ GeV
- 2 leading lepton have the same charge
- $\geqslant$ 4 jets with $p_T > 50$ GeV

2 signal regions :

SR1 : $\not{E}_T > 150$ GeV

SR2 : $\not{E}_T > 150$ GeV and $m_T > 100$ GeV



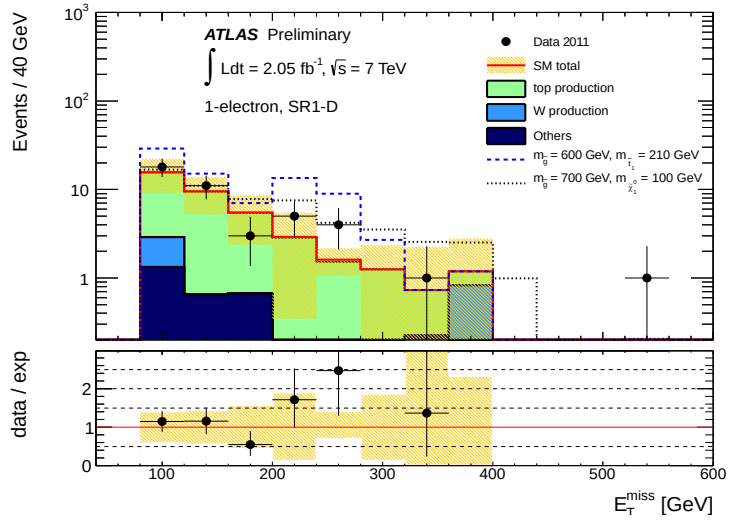
1 lepton + b-jets

- = 1 lepton with $p_T > 25$ (e), 20 (μ) GeV
- $\geqslant$ 4 jets with $p_T > 50$ GeV, $\geqslant$ 1 b-jet
- $m_T > 100$ GeV

2 signal regions :

SR1 : $m_{eff} > 700$ GeV and $\not{E}_T > 80$ GeV

SR2 : $m_{eff} > 700$ GeV and $\not{E}_T > 200$ GeV



Gluino mediated stop pair production : interpretation

Phenomenological MSSM model

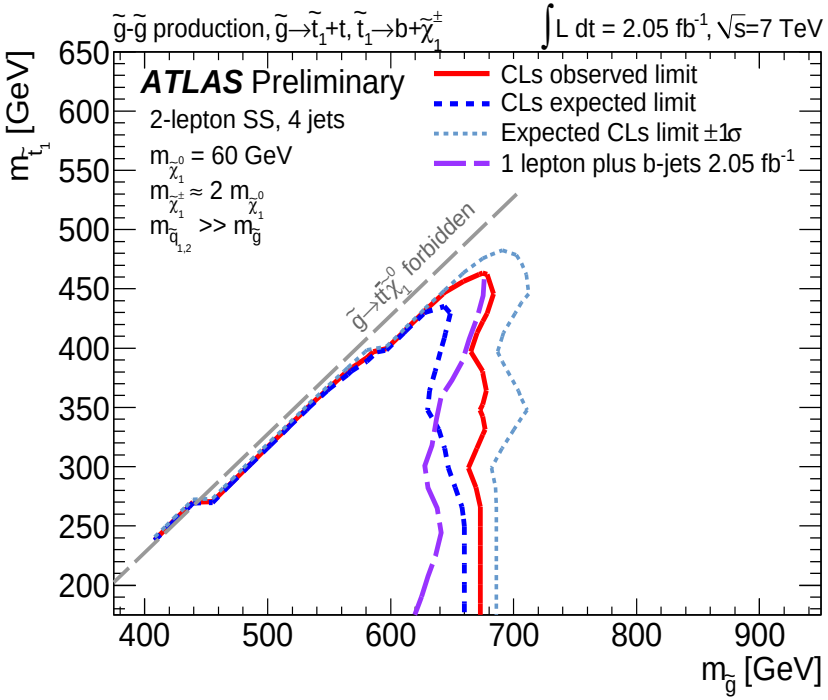
- Production : $\tilde{g}\tilde{g} + \tilde{t}_1\tilde{t}_1$
- Mass spectrum : $m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_{\tilde{g}}$

$m_{\tilde{\chi}^0} = 60$ GeV, $m_{\tilde{\chi}_1^\pm} \approx 2m_{\tilde{\chi}_1^0}$

- Decays :

$\tilde{g} \to \tilde{t}_1 t, \quad \tilde{t}_1 \to b + \tilde{\chi}_1^\pm, \quad \tilde{\chi}_1^\pm \to W^\pm + \tilde{\chi}_1^0$

▶ Exclude $m_{\tilde{g}} < 650$ GeV for $m_{\tilde{t}_1} < 450$ GeV



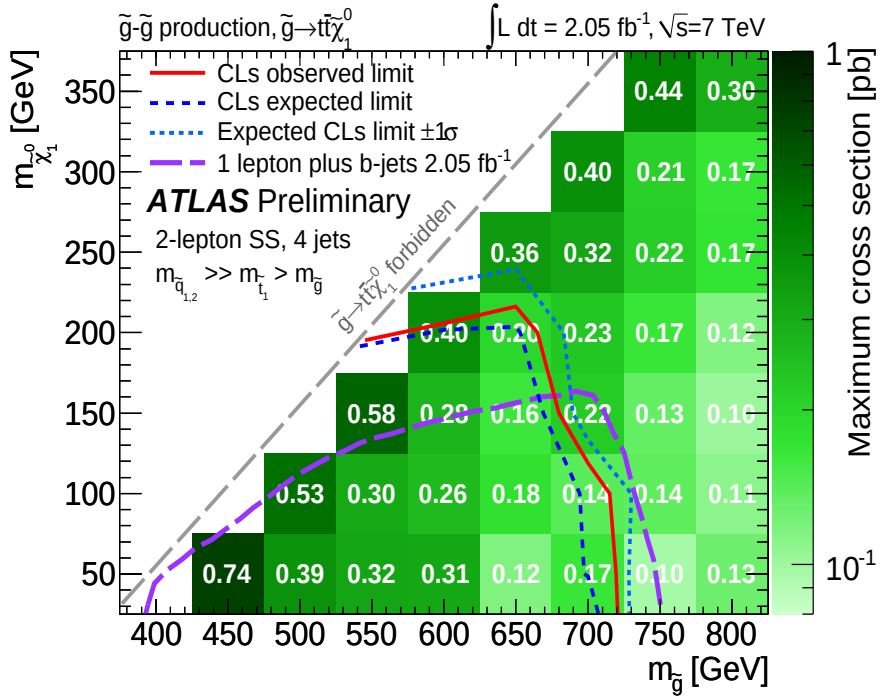
Simplified model

- Production : $\tilde{g}\tilde{g}$
- Mass spectrum : $m_{\tilde{\chi}^0} < m_{\tilde{g}} < m_{\tilde{t}_1}$
- Decays :

$\tilde{g} \to t\bar{t} + \tilde{\chi}_1^0$ via offshell stop decay

▶ Exclude $m_{\tilde{g}} < 750$ GeV for $m_{\tilde{\chi}_1^0} = 0$ GeV

▶ Extract cross section UL : $\sigma_{95}^{obs} = \frac{N_{95}^{obs}}{\mathcal{L}.\varepsilon\mathcal{A}}$



Summary

- Strong interest in third generation searches because of "naturalness" argument
- Variety of searches with ATLAS looking at third generation squarks and sleptons
- No significant excess observed over SM expectations with 2 fb^{-1} of data

▶ Set limits for different scenarios :

• Direct sbottom production : Exclude $m_{\tilde{b}_1} < 390$ GeV for $m_{\tilde{\chi}_1^0} = 0$ GeV

• Gluino mediated sbottom production :

◦ $m(\tilde{\chi}_1^0) < m_{\tilde{b}_1} < m_{\tilde{g}}$: Exclude $m_{\tilde{g}} < 920$ GeV for $m_{\tilde{b}_1} < 800$ GeV

◦ $m(\tilde{\chi}^0) < m_{\tilde{g}} < m_{\tilde{b}_1}$: Exclude $m_{\tilde{g}} < 900$ GeV for $m_{\tilde{\chi}_1^0} < 300$ GeV

• Gluino mediated stop production :

◦ $m(\tilde{\chi}_1^0) < m_{\tilde{t}_1} < m_{\tilde{g}}$: Exclude $m_{\tilde{g}} < 650$ GeV for $m_{\tilde{t}_1} < 450$ GeV

◦ $m(\tilde{\chi}^0) < m_{\tilde{g}} < m_{\tilde{t}_1}$: Exclude $m_{\tilde{g}} < 750$ GeV for $m_{\tilde{\chi}_1^0} = 0$ GeV

• Gluino/squark mediated stau production in GMSB : Exclude $\Lambda < 31$ TeV for all $\tan\beta$

- New results with the full 2011 data set (4.7 fb^{-1}) will be released soon...

BACK-UP

Gluino mediated sbottom / stop pair production : interpretation

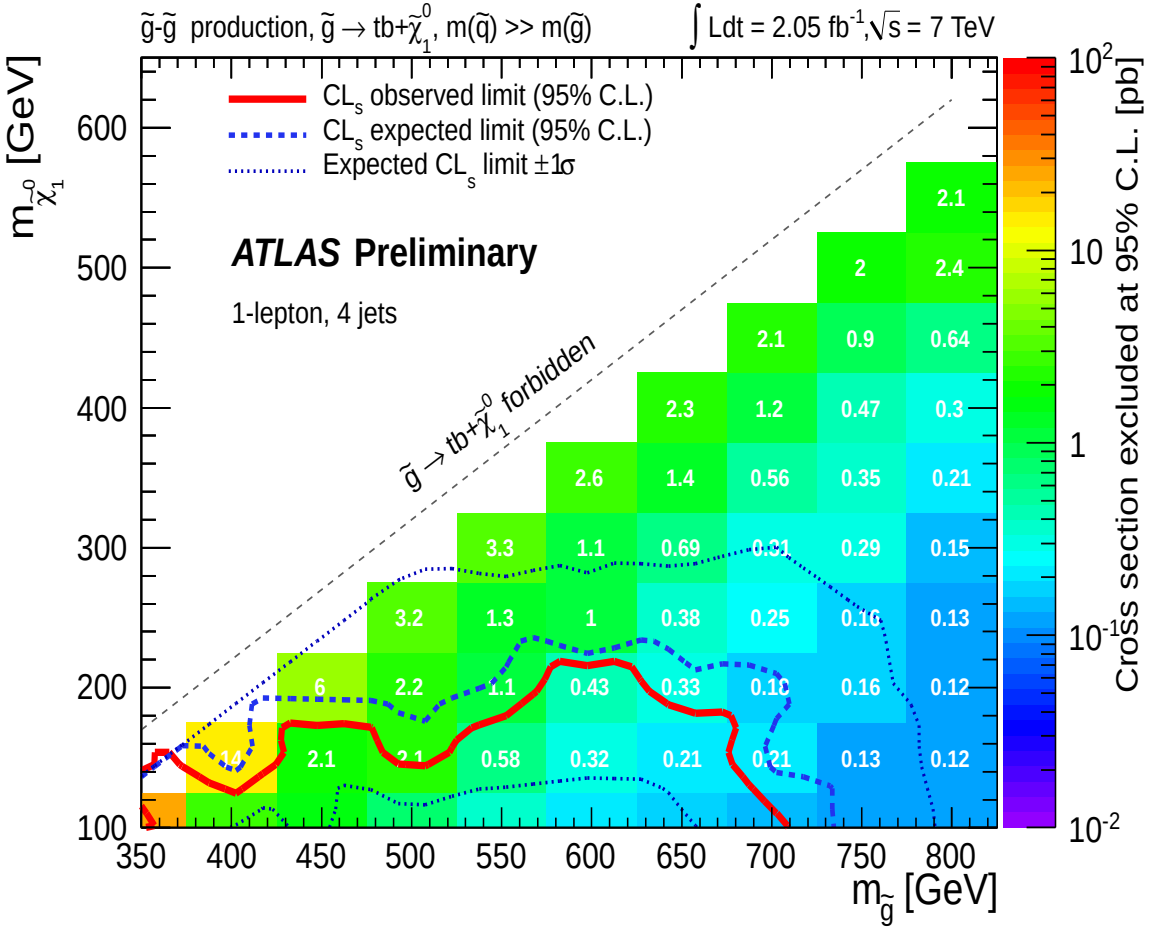
■ $1\ell + b$-jets analysis interpreted for another simplified model in the ($m_{\tilde{g}}$, $m_{\tilde{\chi}_1^0}$) plane

Hypotheses :

• $\tilde{g}$ 3 body decay into $bt\tilde{\chi}_1^{\pm}$
via offshell stop or sbottom decay

• $m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} = 2$ GeV
$\Rightarrow \tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 +$ soft ff'

• $\tilde{\chi}_0^{\pm} < 103$ GeV are excluded
by the LEP.

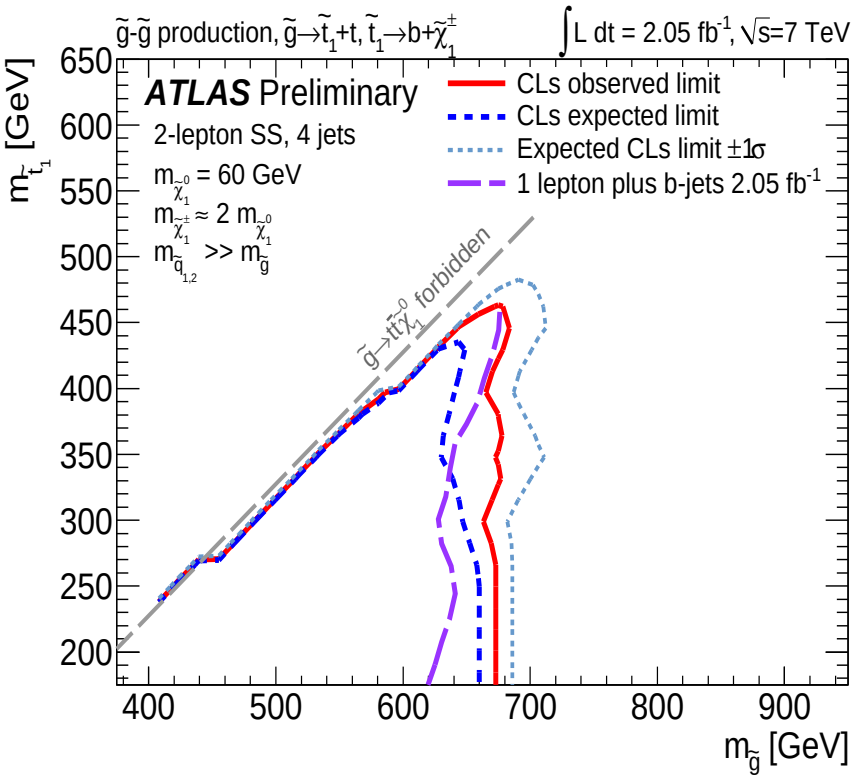


► Gluino masses below 720 GeV are excluded for a neutralino mass of 50 GeV

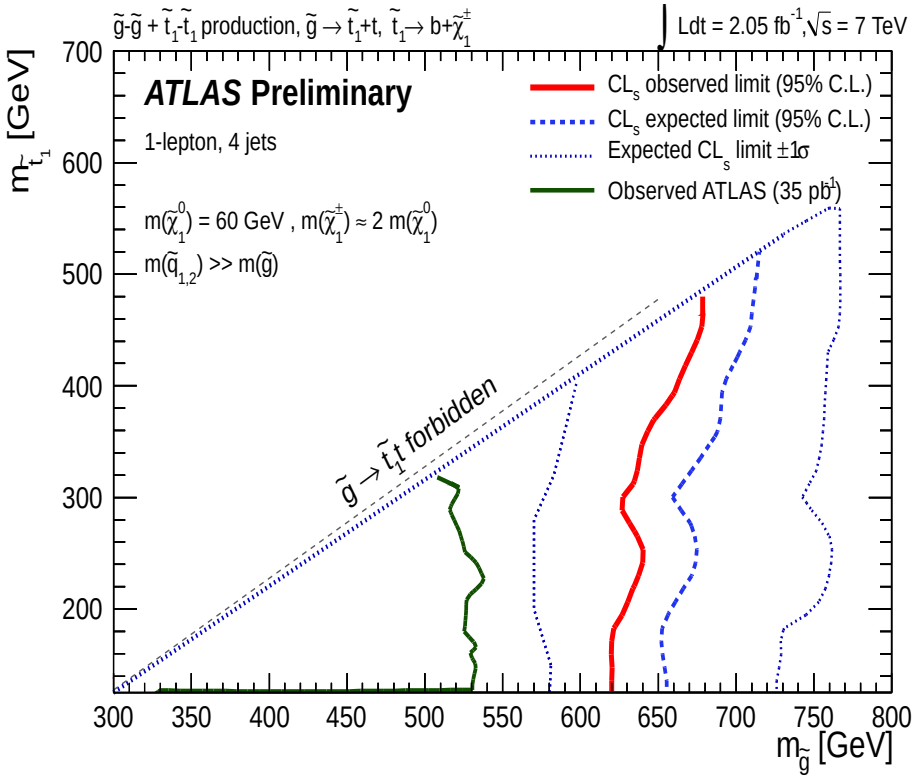
► Extract the 95% C.L. cross section upper limits : $\sigma_{95}^{obs} = \frac{N_{95}^{obs}}{\mathcal{L}.\varepsilon\mathcal{A}}$

Gluino mediated stop pair production : MSSM model

2 same-sign leptons

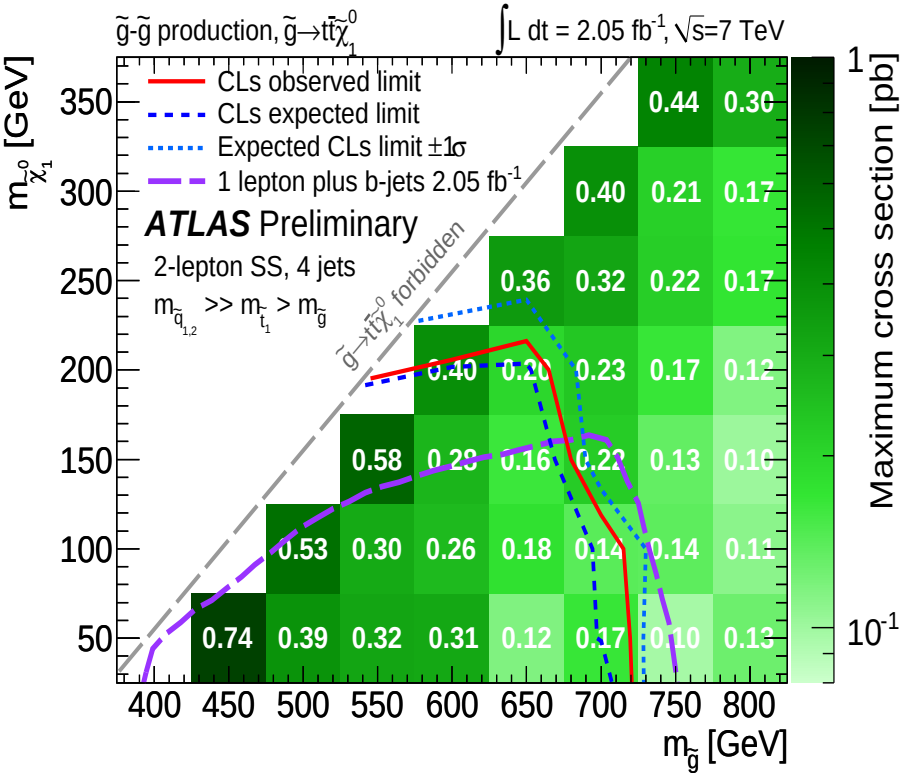


1 lepton + *b*-jets

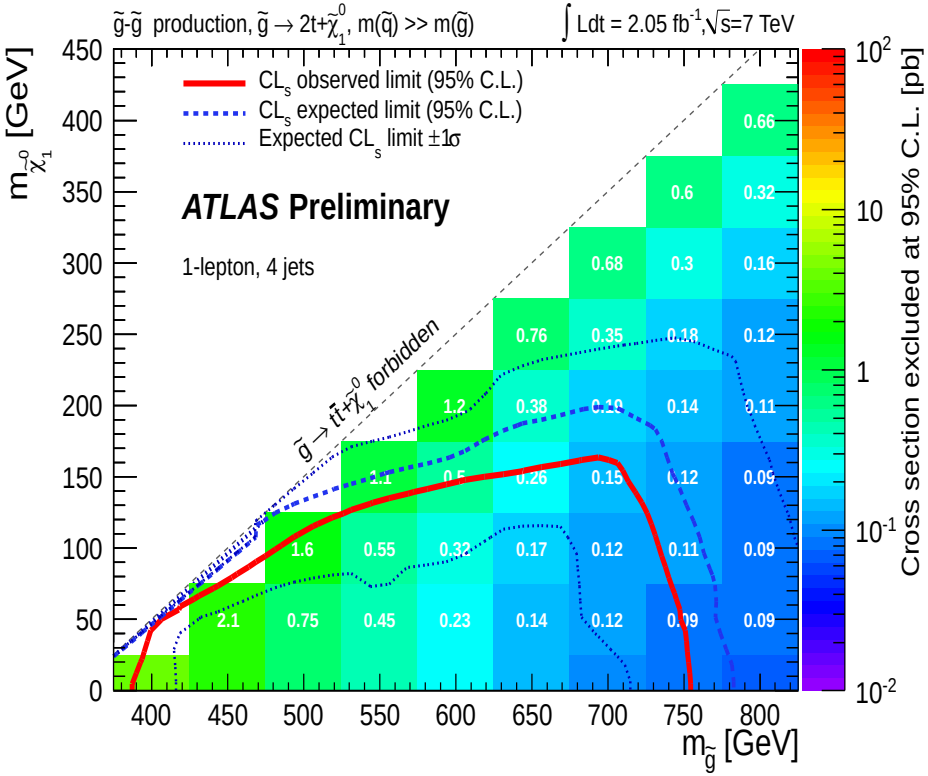


Gluino mediated stop pair production : simplified model

2 same-sign leptons



1 lepton + b-jets



Hadronic τ and b-jets identification

Hadronic τ (ATLAS-CONF-2011-152)

- Boosted Decision Tree on jets

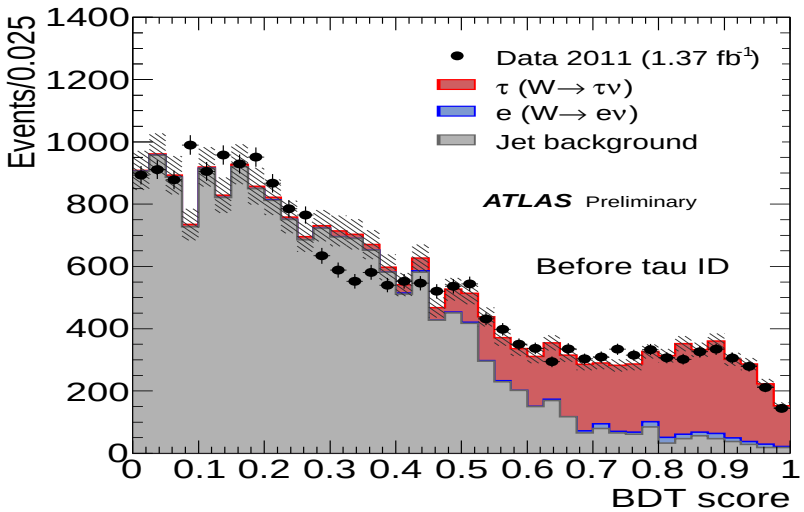
based on shower-shape and tracking variables + transition radiation and calorimetry cuts to reject electrons

- Operating point :
  - Loose used in the 2 τ analysis :

ε = 60% ; jet rejection 20-30

  - Tight used in the 1 τ analysis :

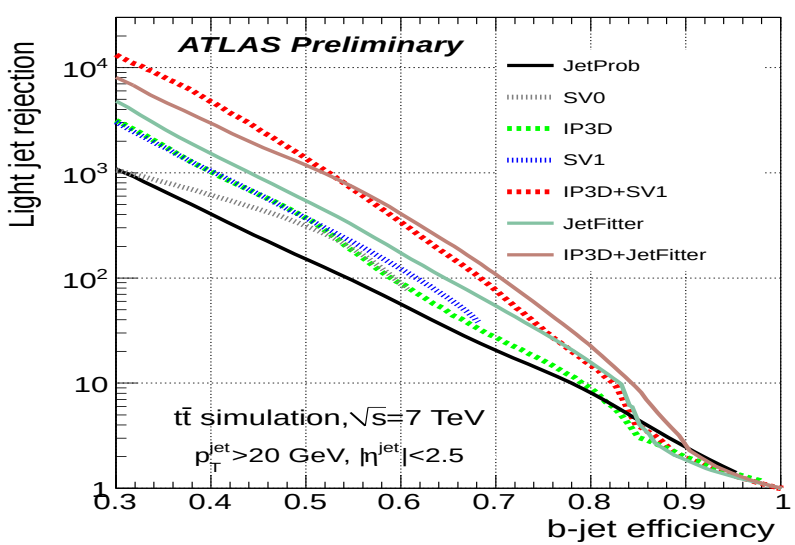
ε = 30-50% ; jet rejection 30-200



b-tagging (ATL-CONF-2011-102)

- IP3D + JetFitter algorithm
  - IP3D : based on the transverse and longitudinal impact parameter significance of the tracks d_0/σ_{d0} and z_0/σ_{z0}
  - JetFitter : based on the topology of b and c decay inside the jet

- Operating point :
  - Efficiency of 60%
  - Mistag rate for light / gluon jets $< 1\%$



Direct sbottom production : results

0ℓ + b-jets + $\not{E}_T$ analysis with 2 fb^{-1} : arXiv :1112.3832

m_{CT} GeV	top, W+HF TF (MC)	Z+HF TF (MC)	Others MC+DD	Total SM	Data	obs (exp) σ_{vis} [fb]
0	67 ± 10 (60 ± 25)	23 ± 8 (16 ± 9)	3.6 ± 1.5	94 ± 16 (80 ± 35)	96	
100	36 ± 10 (34 ± 16)	23 ± 9 (12 ± 7)	3.1 ± 1.6	62 ± 13 (49 ± 25)	56	13.4 (15.2)
150	12 ± 5 (13 ± 8)	12 ± 6 (8.3 ± 4.7)	2.7 ± 0.9	27 ± 8 (24 ± 13)	28	9.6 (9.2)
200	3.2 ± 1.6 (4.1 ± 3.4)	3.9 ± 3.2 (2.8 ± 1.5)	1.0 ± 0.9	8.1 ± 3.5 (8.0 ± 4.9)	10	5.6 (4.7)

Gluino mediated sbottom production : results

ATLAS-CONF-2012-003

SR	nb b-jets m_{eff} [GeV]	Top d-d (MC)	W/Z di-boson	multi-jet/	Total	Data	obs (exp) σ_{vis} [fb]
SR0-A1	$\geqslant 1$ > 500	705 ± 110 (725)	248 ± 150	53 ± 21	1000 ± 180	1112	282 (251)
SR0-B1	$\geqslant 1$ > 700	119 ± 26 (122)	67 ± 42	7.3 ± 4.7	190 ± 50	197	65 (65)
SR0-C1	$\geqslant 1$ > 900	22 ± 9 (22)	16 ± 11	1.5 ± 1	39 ± 14	34	15.4 (16.9)
SR0-A2	$\geqslant 2$ > 500	272 ± 70 (212)	22.5 ± 15	21 ± 12	316 ± 72	299	61 (66)
SR0-B2	$\geqslant 2$ > 700	47 ± 11 (37)	4.5 ± 3	2.8 ± 1.7	54 ± 11	43	14.4 (15.0)
SR0-C2	$\geqslant 2$ > 900	8.5 ± 3 (6.6)	0.8 ± 1	0.5 ± 0.4	9.8 ± 3.2	8	4.3 (5.0)

Gluino mediated stop production : results

2 same-sign leptons (ATLAS-CONF-2012-004)

	SR1	SR2
m_T [GeV]	-	> 150
$t\bar{t}$+X	0.37 ± 0.26	0.21 ± 0.16
Diboson	0.05 ± 0.02	0.02 ± 0.01
Fake-lepton	0.34 ± 0.20	< 0.17
Charge mis-ID	0.08 ± 0.01	0.039 ± 0.007
Total SM	0.84 ± 0.33	0.27 ± 0.24
Observed	0	0
$\sigma_{\text{vis}}^{\text{obs}}$ [fb]	<1.6	<1.5
$\sigma_{\text{vis}}^{\text{exp}}$ [fb]	$<1.7^{+0.5}_{-0.1}$	$<1.6^{+0.2}_{-0.1}$

1 lepton + b-jets (ATLAS-CONF-2012-003)

SR	$\not{E}_T$ [GeV]	SM background	Data	obs (exp) σ_{vis} [fb]
SR1-D (e)	> 80	39 ± 12 (39)	43	22.2 (20.5)
SR1-D (μ)		38 ± 14 (37)	38	
SR1-E (e)	> 200	8.1 ± 3.4 (7.9)	11	8.5 (7.5)
SR1-E (μ)		6.3 ± 4.2 (6.1)	6	

Gluino and squark mediated stau production : results

analysis	SM background	Observed	obs σ_{vis} [fb]
1 τ analysis (ATLAS-CONF-2012-005)	13.2 ± 4.2	11	4.0
2 τ analysis (ATLAS-CONF-2012-002)	5.3 ± 2.6	3	2.7