ATLAS stop searches with b-jets (direct and gluino-mediated)

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On behalf of the ATLAS collaboration

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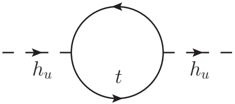
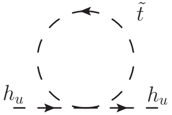
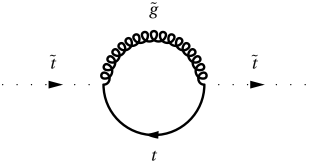
Motivation

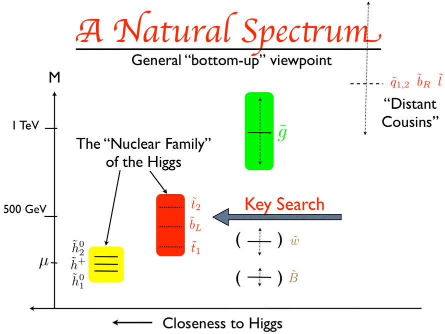
■ An important motivation for EW-scale supersymmetry is that it can solve the hierarchy problem without "unnatural" fine-tuning in the Higgs sector provided that the stop is light enough





▶ the gluino not much heavier than ∽ 1.5 TeV due to the radiative correction to $m_{\tilde{t}}$:





From Lawrence Hall, October 2011

■ Mixing of $(\tilde{f}_L, \tilde{f}_R)$ is larger in the third generation $\Longrightarrow$ $\tilde{t}_1$ and $\tilde{b}_1$ are expected to be lighter than other squarks

Strategy for stop searches

■ Both $\tilde{t}_1$ and $\tilde{g}$ are expected to be “relatively light

$\rightarrow$ a few hundred GeV for $m_{\tilde{t}_1}$ and up to 1.5 GeV for $m_{\tilde{g}}$

▶ 2 strategies for stop searches :

• **If the gluino is light enough :**

$\Longrightarrow$ Large $\tilde{g}\tilde{g}$ and we can look at gluino mediated $\tilde{t}_1$ production

▶ Very rich final states with many jets, b-jets, leptons and $\not{E}_T$

• **If only $\tilde{t}_1$ light :**

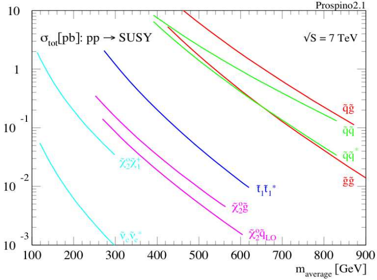
$\Longrightarrow$ Look at direct $\tilde{t}_1$ pair production :

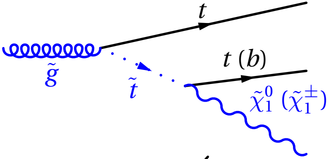
▶ challenging final states more similar to SM processes :

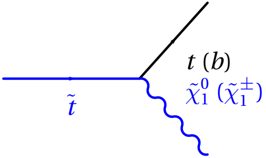
∘ $\tilde{t} \rightarrow t + \tilde{\chi}_1^0$: $t\bar{t}$ + $\not{E}_T$

∘ $\tilde{t} \rightarrow b + \tilde{\chi}_1^+$: 2 b-jets + 2 W + $\not{E}_T$

∘ $\tilde{t} \rightarrow c + \tilde{\chi}_1^0$: 2 c-jets + $\not{E}_T$







General approach in stop searches

The 2 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

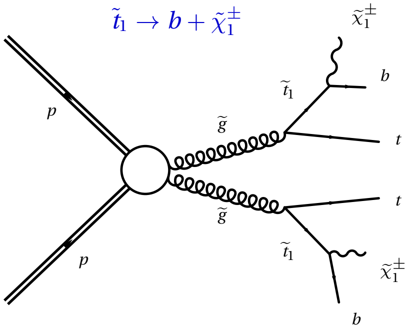
- Detector related uncertainties : jet energy scale/resolution, b-tagging efficiency, lepton ID...
- Theoretical uncertainty : MC generator, ISR/FSR, PDF, factorisation/renormalisation scales ...

IV Interpretation of the results

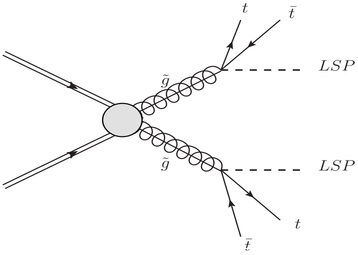
If no excess is observed in data, derive exclusion limits at 95% C.L. using CL_s in a model independent way or in the context of different susy scenarios

Search for gluino mediated stop pair production

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



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



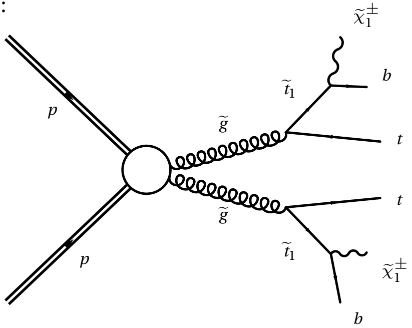
1-ℓ + b-jets + $\not{E}_T$ analysis with 2 fb^{-1} : ATLAS-CONF-2012-003

Description of the analysis

■ 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, $\not{E}_T$

■ Event selection based on 1 lepton + b-jets analysis :



- = 1 lepton with $p_T > 25$ (e), 20 (μ) GeV
- $\geqslant 4$ jets with $p_T > 60, 50, 50, 50$ GeV
- $\geqslant 1$ b-jet with $p_T > 50$ GeV, $\varepsilon = 60\%$
- $m_T > 100$ GeV
- $m_{eff} > 700$ GeV

2 signal regions :

- SR1 : $\not{E}_T > 80$ GeV
- SR2 : $\not{E}_T > 200$ GeV

■ Background estimation :

◦ Multi-jets : fully-data-driven estimate with the "matrix method"

◦ Other MS backgrounds : semi-data-driven estimate based on MC transfer factors from a control region to the signal regions

Estimation of the multi-jets background : fully-data-driven

■ 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) and loose (relaxed)

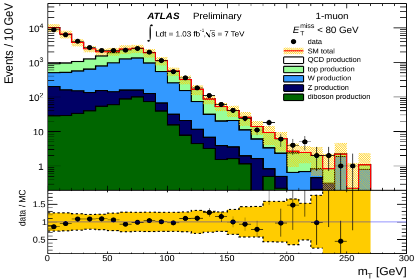
II Measure in data the "loose $\to$ tight" ε for real/fake leptons

III Estimate $N^{tight}_{fake} = \varepsilon_{fake} N^{loose}_{fake}$ by counting the number of events in each sample :

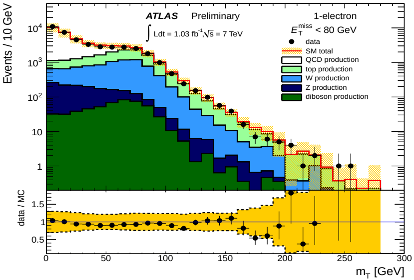
$$\begin{aligned} N^{loose} &= N^{loose}_{real} + N^{loose}_{fake} \\ N^{tight} &= \varepsilon_{real} N^{loose}_{real} + \varepsilon_{fake} N^{loose}_{fake} \end{aligned}$$

■ Validation of the method in QCD control region with $\geqslant 1$ b-jet and $\not{E}_T < 80$ GeV

Muon channel



Electron channel



Estimation of other SM backgrounds : semi-data-driven

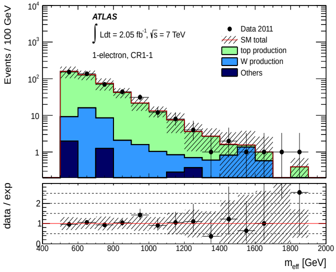
■ The dominant top and W+jets backgrounds are estimated using a semi-data method based on Transfer Factors from a background enhanced control region (CR) to the signal regions (SR) :

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

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

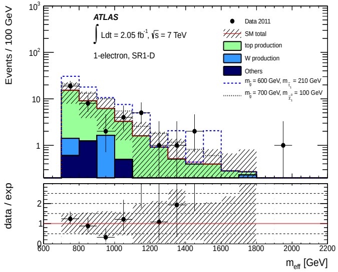
► The background enhanced control region is obtained by reversing the m_T cut

CR : $40 < m_T < 100$ GeV



$$\xrightarrow[T_f \backsim 0.09]{T_f^{t\bar{t}}[CR) \to SR]}$$

SR : $m_T > 100$ GeV



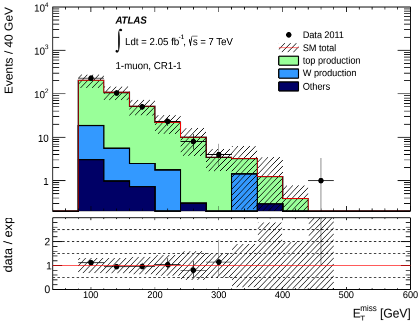
Estimation of other SM backgrounds : semi-data-driven

■ The control region is defined with similar cuts as in the SR, except the m_T which is reversed and the m_{eff} and $\not{E}_T$ cuts which are relaxed to minimize the signal contamination :

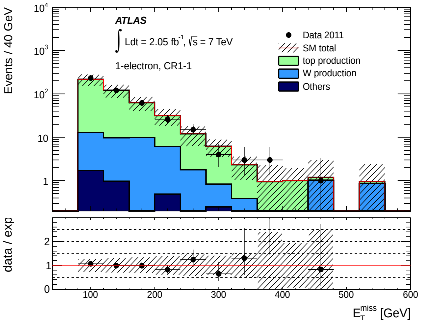
- = 1 lepton with $p_T > 25$ (e), 20 (μ) GeV
- $\geqslant 4$ jets with $p_T > 60, 50, 50, 50$ GeV
- $\geqslant 1$ b-jet
- $40 < m_T < 100$ GeV
- $m_{eff} > 500$ GeV
- $\not{E}_T > 80$ GeV

	top Z+jets	W+jets	multi-jet/ di-boson	SM	data
e	414	40	3.6	460 ± 100	465
μ	377	25	5.2	410 ± 110	420

Muon channel



Electron channel



Systematic uncertainties

■ Detector related uncertainties (amount to 10-30% for the signal)

Jet Energy Scale and Resolution, b-tagging, Lepton ID, trigger, luminosity

■ Theoretical uncertainties

top production :

- MC generator : difference between MCAtNLO (nominal) and Powheg+Herwig ($t\bar{t}$ only)
- Parton shower : difference between Powheg + Herwig/Jimmy and Powheg+Pythia ($t\bar{t}$ only)
- ISR/FSR : use AcerMC + pythia samples with different ISR/FSR parameters
- $t\bar{t} + b\bar{b}$ or W/Z : uncertainty of 100%

W,Z + jets production :

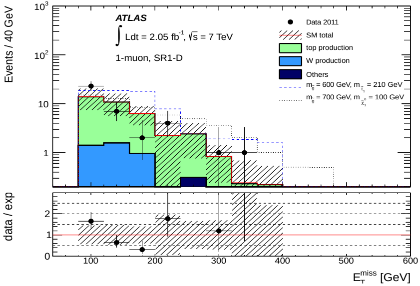
- vary the relative cross sections of Alpgen samples with different numbers of partons
- W+$b\bar{b}$: uncertainty of about 70%

Signal : (amount to 20-35% in the vicinity of the expected limits) :

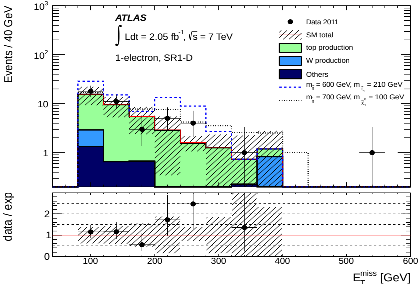
- Renorm/fact scale : vary them in PROSPINO between half and twice their default values
- PDF : provided by CTEQ6

SR	JES/ JER	b-tag	lepton ID	theory	others	total
SR1-D	6%	1%	1%	34%	7%	35%
SR1-E	7%	1%	1%	53%	10%	55%

Muon channel



Electron channel



- Good agreement between data and SM background prediction.
- Derive model independ limits on the number of hypothetical signal events in the signal regions

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	

Limits for MSSM in the $(m_{\tilde{t}_1}, m_{\tilde{g}})$ plane

► Results are then converted into exclusion limits at 95% C.L. with CL_S for a constrained MSSM in the $(m_{\tilde{t}_1}, m_{\tilde{g}})$ plane

- Production : $\tilde{g}\tilde{g} + \tilde{t}_1\tilde{t}_1$
- Mass spectrum :

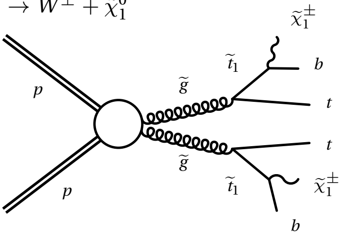
$m_{\tilde{\chi}_1^0} < m_{\tilde{t}_1} < m_{\tilde{g}}$

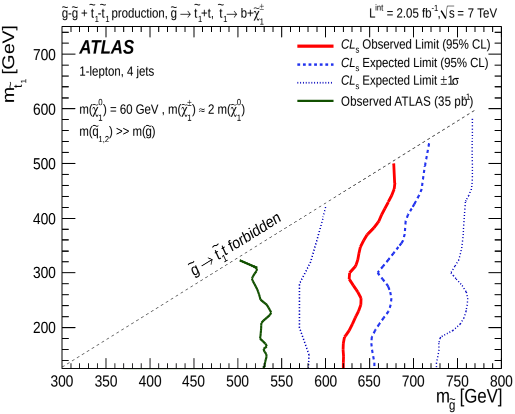
$m_{\tilde{\chi}^0} = 60$ GeV, $m_{\tilde{\chi}_1^\pm} \approx 2m_{\tilde{\chi}_1^0}$

- Decays :

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

$\tilde{\chi}_1^\pm \to W^\pm + \tilde{\chi}_1^0$





► Obs (exp) limits at 95% C.L. on $m_{\tilde{g}}$ at 620 (650) GeV for $m_{\tilde{t}_1}$ below 430 (460) GeV

Simplified model in the $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0})$ plane

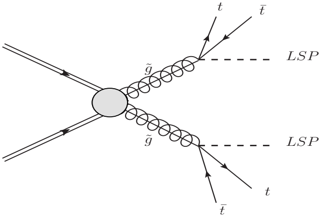
■ Results also interpreted in the context of simplified models in the $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0})$ plane

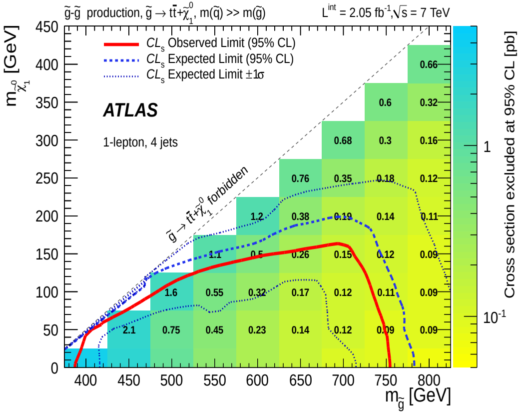
- Production : $\tilde{g}\tilde{g}$
- Mass spectrum :

$m_{\tilde{\chi}^0} < m_{\tilde{g}} < m_{\tilde{t}_1}$

- Decays :

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





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

▶ Observed (expected) limits at 95% C.L. on $m_{\tilde{g}}$ at 750 (770) GeV for $m_{\tilde{\chi}_1^0}$ of 50 GeV

▶ Observed (expected) limits at 95% C.L. on $m_{\tilde{\chi}_1^0}$ at 160 (200) GeV for $m_{\tilde{g}}$ of 700 GeV

Simplified model in the $(m_{\tilde{g}}, m_{\tilde{\chi}_1^0})$ plane

■ Results also interpreted for a similar simplified models with $\tilde{g}$ decay into $tb\tilde{\chi}_1^0$

- Production : $\tilde{g}\tilde{g}$
- Mass spectrum :

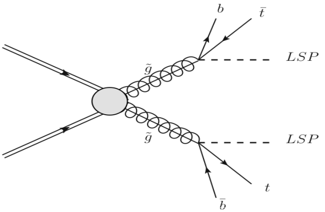
$m_{\tilde{\chi}^0} < m_{\tilde{g}} < m_{\tilde{t}_1}, m_{\tilde{b}_1}$

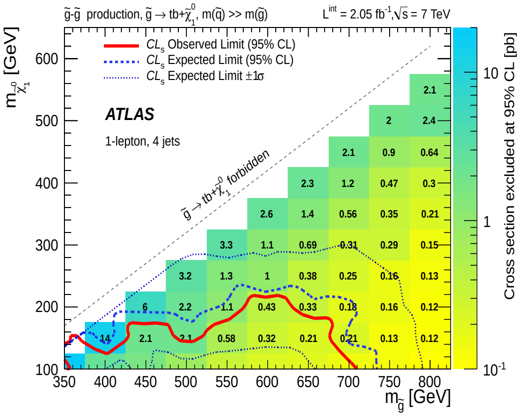
$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 2$ GeV

- Decays :

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

$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0$ + soft ff'

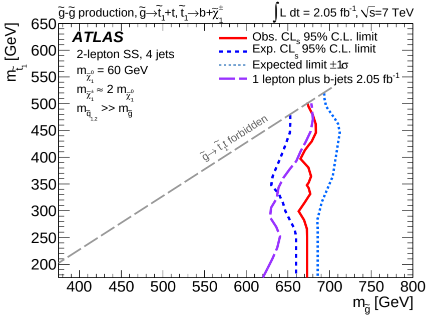


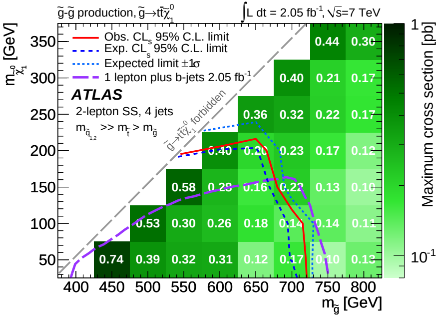


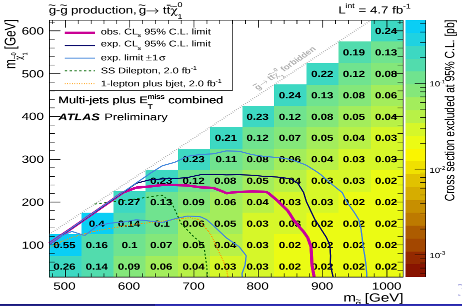
$\tilde{\chi}_0^\pm < 103$ GeV are already excluded by the LEP .

► Observed (expected) limits at 95% C.L. on $m_{\tilde{g}}$ at 710 (740) GeV for $m_{\tilde{\chi}_1^0}$ of 100 GeV

Other gluino mediated stop pair production searches







- **2 lepton SS analysis with 2.05 fb^{-1}**
  - ▶ See T. Sarangi's talk
- **6-9 jets analysis with 4.7 fb^{-1}**
  - ▶ See D. Nguyen's talk

Direct stop pair production in the GMSB framework

dilepton OS + $\not{E}_T$ analysis with 2 fb^{-1} (ATLAS-CONF-2012-036)

Description of the signal and event selection

■ Search for direct stop pair production in the context of a specific Gauge-mediated-like SUSY model *(M. Asano et al., JHEP 12, 019 (2010))*

■ Motivation : in GMSB models, an upper bound $m_{\tilde{t}_1} < 400$ GeV can be obtained by imposing the absence of significant fine tuning ($\Delta^{-1} = m^2_{H_u}|_{\mathrm{rad}}/2m^2_h > 10$ %) and $M_{\mathrm{mess}} \sim 10$ TeV.

- Production : $\tilde{t}_1\tilde{t}_1$ production
- Mass spectrum : gravitino LSP ($m_{\tilde{G}} \ll 1$ KeV), $\tilde{\chi}^0_1$ NLSP
- decay : with $\tilde{t}_1 \to b\tilde{\chi}^{\pm}_1$ or $\tilde{t}_1 \to t\tilde{\chi}^0_{1,2}$ if kinematically allowed

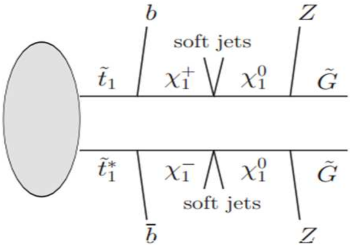
Assume $\tilde{\chi}^0_1$ purely higgsino-like with $\tilde{\chi}^0_1 \to Z/h + \tilde{G}$, with BR[$\tilde{\chi}^0_1 \to Z\tilde{G}$] between 1 and 0.65 for $100 < m_{\tilde{\chi}^0_1} < 350$ GeV

▶ Signature : 2 b-jets, 2 same-flavour leptons and large $\not{E}_T$

- Event selection : dilepton OS, SF :
- Exactly 2 leptons (e,μ) with OS and SF
- $86 < M_{\ell\ell} < 96$ GeV
- $\geqslant 2$ jets with $p_T > 60, 50$ GeV
- $\geqslant 1$ b-jets with $p_T > 50$ GeV

2 signal regions :

- SR1 : $\not{E}_T > 50$ GeV : large $\Delta m(\tilde{t}_1, \tilde{\chi}^0_1)$
- SR2 : $\not{E}_T > 80$ GeV : small $\Delta m(\tilde{t}_1, \tilde{\chi}^0_1)$



Estimation of the SM backgrounds

- $t\bar{t}$ + single top : semi-data-driven method based on transfer factors
- Z + heavy flavour : same topology than signal

$\rightarrow$ estimated from MC and validated in data in a Z dominated validation region

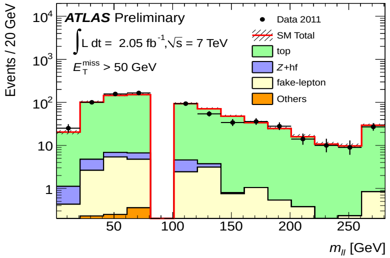
- Multi-jets : data-driven estimate with the matrix method
- Subdominant backgrounds : based on MC simulations

Top CR

Obtained by reversing the $m_{\ell\ell}$ cut :

$15 < M_{\ell\ell} < 81$ GeV or 105 GeV $< M_{\ell\ell}$

uncertainty between 11 and 13 %

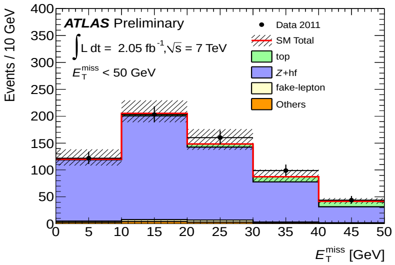


Z + hf VR

Define a validation region at low $\not{E}_T (< 50$ GeV)

large signal contamination at low $m_{\tilde{\chi}_1^0}$

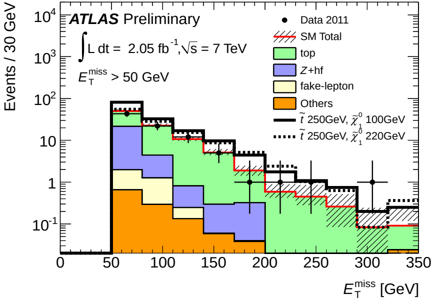
uncertainty of 55% on the cross-section,
+ 24% uncertainty by additional jet



Results

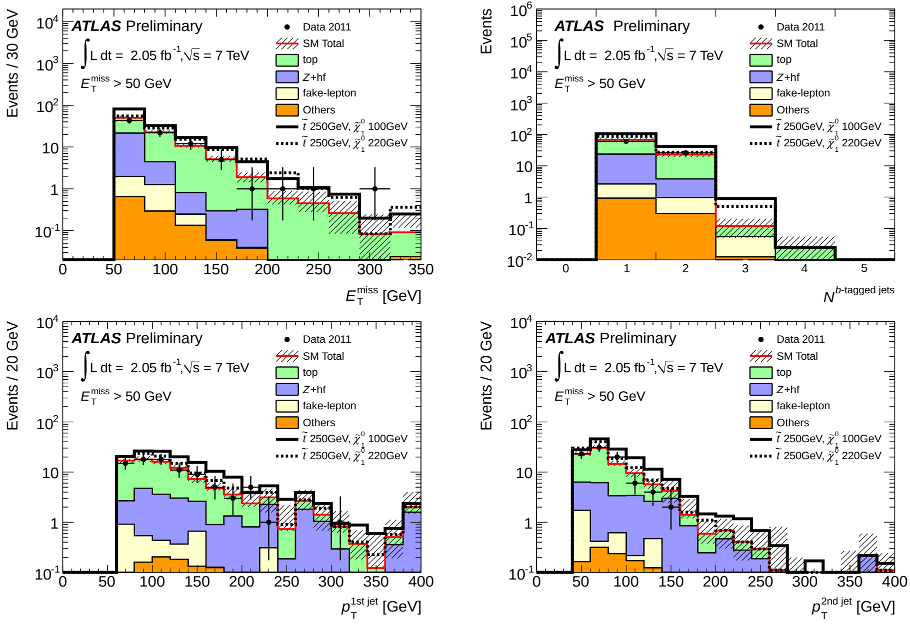
- ▶ Good agreement between data and SM background prediction.
- ▶ Derive model independ limits on the number of hypothetical signal events in the signal regions

	SR1	SR2
95% C.L. upper limits : observed (expected)		
events	37.2 (40.6)	19.8 (17.8)
visible σ [fb]	18.2 (19.8)	9.7 (8.7)



	SR1	SR2
ee channel		
Data	39	20
SM	36.2±8.5	14.1±3.0
top	23.8±4.8	11.9±2.8
Z+hf	9.4±7.0	0.9±0.8
fake lepton	2.4±0.9	1.1±0.6
Others	0.5 ± 0.5	0.2 ± 0.2
$\mu\mu$ channel		
Data	47	23
SM	55 ± 12	26.6±5.1
top	40.4 ± 6.2	22.9 ± 4.3
Z+hf	14.2±9.9	3.3±2.6
fake lepton	0.00±0.08	0.00±0.07
Others	0.7 ± 0.7	0.3 ± 0.3
ee+$\mu\mu$		
Data	86	43
SM	92±19	40.7 ± 6.0
top	64.3±7.7	34.8 ± 5.0
Z+hf	24±16	4.2±3.2
fake lepton	2.4 ± 0.9	1.1 ± 0.6
Others	1.2 ± 1.2	0.6 ± 0.6

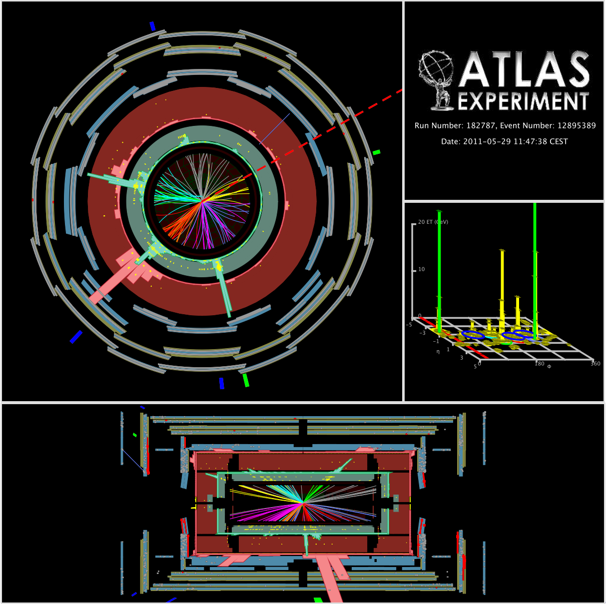
Data/MC comparison in the signal region



Event display

Event display of an event in the signal region :

- $\not{E}_T = 301$ GeV (highest)
- 5 jets
  $p_T = 128, 114, 69, 66, 46$ GeV
- 3^{rd} and 5^{th} jets are b-tagged
- 2 $e \neq$ charge
  $p_T = 54, 28$ GeV
- $m_{ee} = 93.5$ GeV



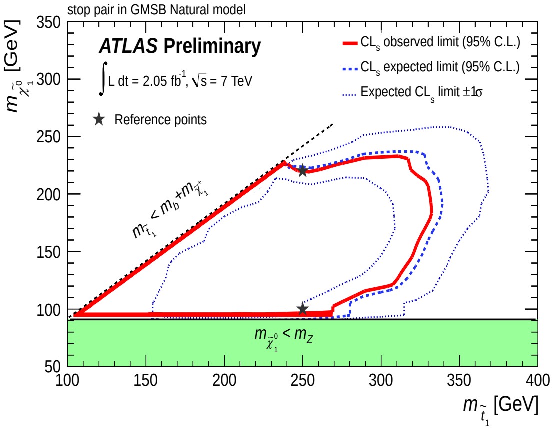
▶ Results are interpreted in the context of GMSB in the $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0})$ plane

Hypotheses :

- $m_{\tilde{q}_3} = m_{\tilde{u}_3} = -A_t/2$
- $\tan\beta = 10$
- $m_{\tilde{q}_{1,2}} > 2$ TeV
- $m_{\tilde{t}_2} \gg m_{\tilde{t}_1}$

$\rightarrow \tilde{t}_1\tilde{t}_1$ production only

- $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$ or $\tilde{t}_1 \rightarrow t\tilde{\chi}_{1,2}^0$
- $\tilde{\chi}_1^0 \rightarrow Z/h\tilde{G}$



▶ Exclude $m_{\tilde{t}_1} < 300$ GeV for $120 < m_{\tilde{\chi}_1^0} < 220$ GeV

▶ Exclude $m_{\tilde{t}_1} < 240$ GeV for all $m_{\tilde{\chi}_1^0}$ masses

Summary

■ Strong interest in third generation searches because of "naturalness" argument

■ Variety of searches with ATLAS looking at gluino mediated and direct stop pair production

■ No significant excess observed over SM expectations with 2 fb^{-1} of data

▶ Set limits for different scenarios :

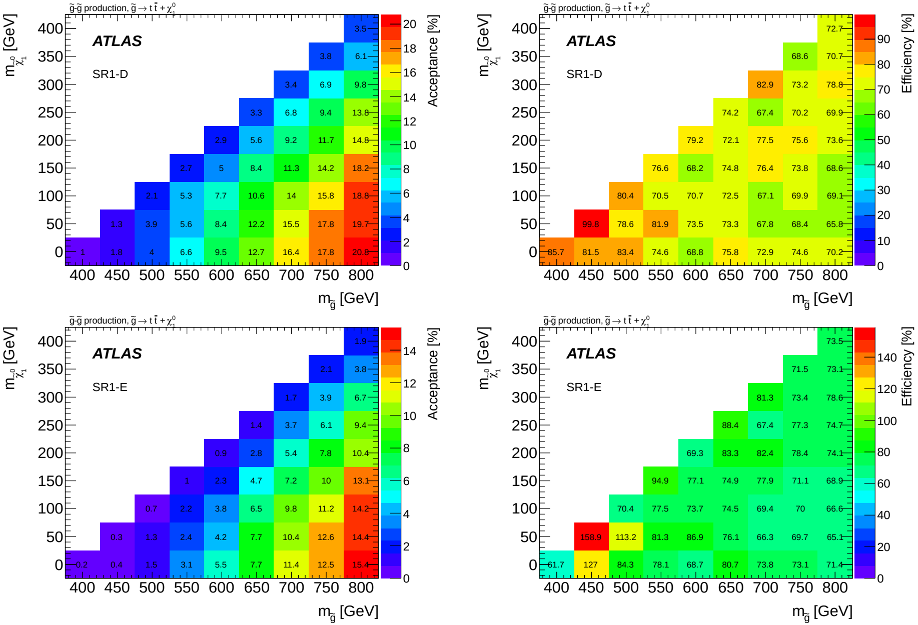
- Gluino mediated stop production :
  - $m(\tilde{\chi}_1^0) < m_{\tilde{t}_1} < m_{\tilde{g}}$: Exclude $m_{\tilde{g}} < 620$ GeV for $m_{\tilde{t}_1} < 430$ GeV
  - $m(\tilde{\chi}^0) < m_{\tilde{g}} < m_{\tilde{t}_1}$: Exclude $m_{\tilde{g}} < 750$ GeV for $m_{\tilde{\chi}_1^0} = 0$ GeV
- Direct stop pair production in GMSB :
  - Exclude $m_{\tilde{t}_1} < 240$ GeV for all $m_{\tilde{\chi}_1^0}$ masses

■ Direct stop searches are more challenging due to similarity with the $t\bar{t}$ final state for low stop masses, and due to the low cross sections for higher stop mass values.

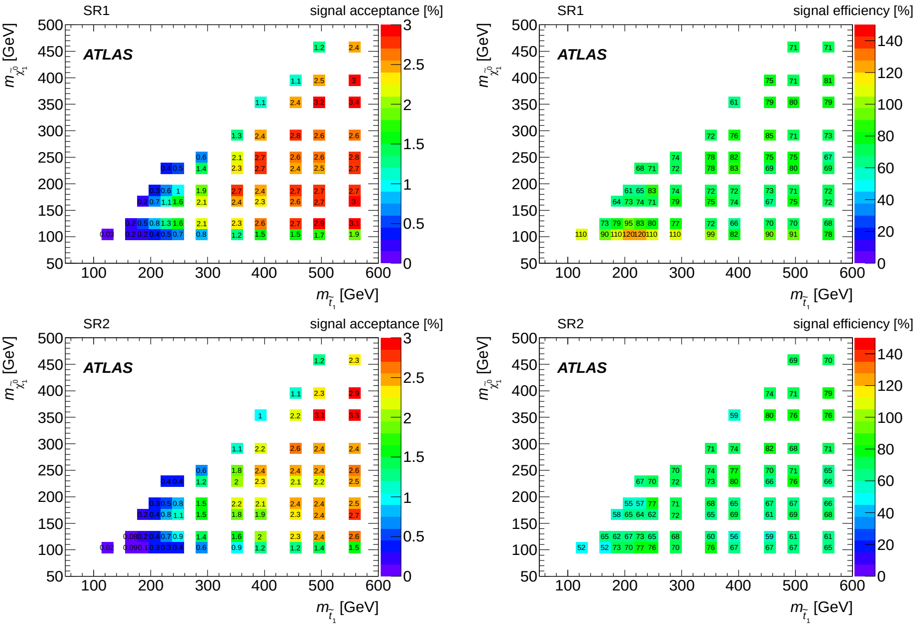
■ New results with the full 2011 data set (4.7 fb^{-1}) will be released soon...

BACK-UP

Acceptance / efficiency for the gluino mediated stop



Acceptance / efficiency for the direct stop



b-jets identification

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 $< 1\%$