ATLAS+CMS searches for SUSY in 3rd generation final states

Implications of LHC results for TeV-scale physics

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28th March 2012

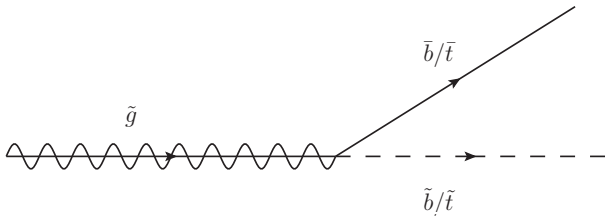
SUSY processes of interest

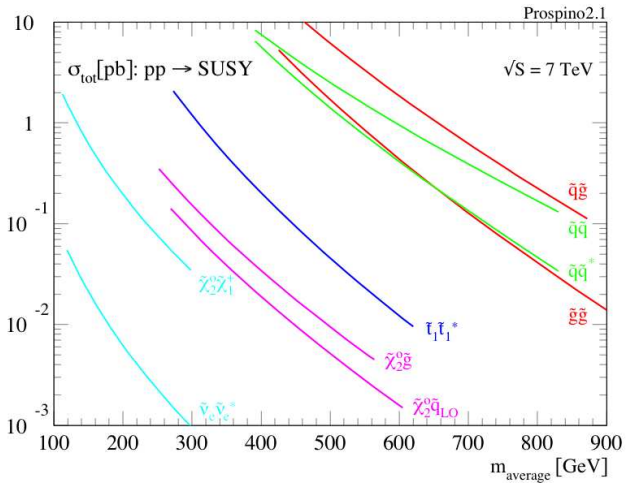
Why look for third generation SUSY?

- Hierarchy problem solved naturally if the 3rd generation is light
- Large mixing in the third generation $\Rightarrow$ low $m(\tilde{\tau}_1), m(\tilde{t}_1)$ and $m(\tilde{b}_1)$

$\tilde{t}_1, \tilde{b}_1$ searches: If $m(\tilde{g})$ accessible at 7 TeV then one can search for Gluino mediated sbottom/stop pair production.

If $m(\tilde{g}) > m(\tilde{b})$ consider:





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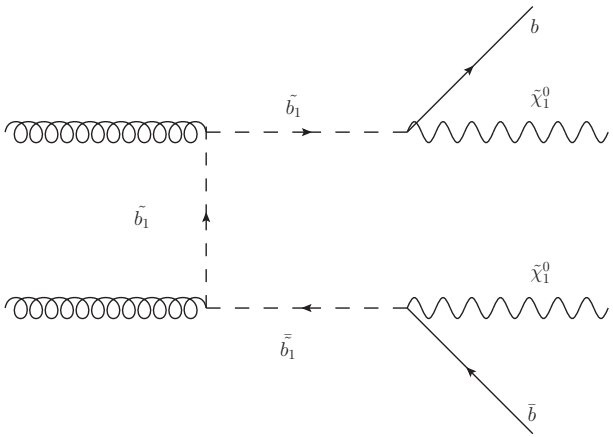
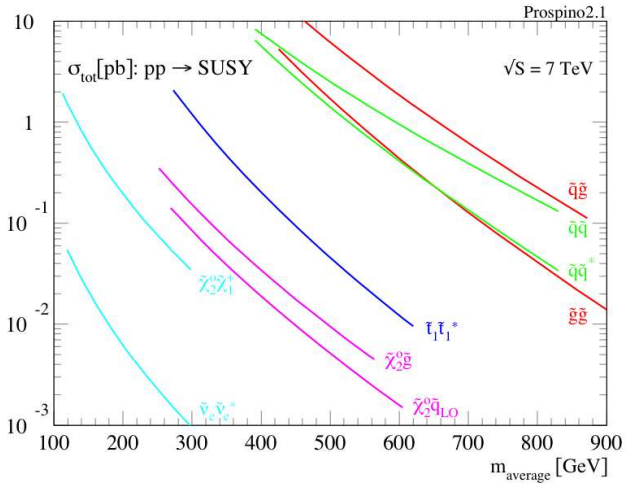
$\tilde{t}_1, \tilde{b}_1$ searches: If $m(\tilde{g})$ not accessible at 7 TeV then one can search for direct sbottom/stop pair production.





Search Strategies

- R-Parity conservation $\Rightarrow$ Missing Transverse Energy (E_T^{miss})
- Cascade decays to LSP $\Rightarrow$ High p_T jets and possibly leptons
- Expect heavy flavour jets $\Rightarrow$ require b-tagged jets
- Exploit signal kinematics via variables like $H_T = \Sigma p_T$, $m_{Eff} = E_T^{Miss} + H_T$, m_{CT}

Analyses Plan

- Define various SRs depending on the signal of interest
- Estimate backgrounds, minimizing the dependence on Monte Carlo simulation
- In the absence of SUSY: set 95 % C.L. limits using CL_s

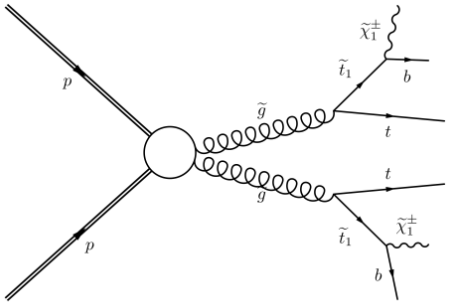
Background Estimation

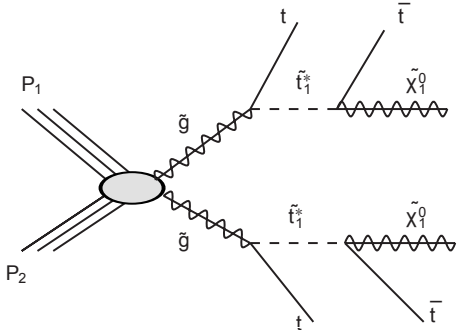
- Dominant backgrounds (ATLAS): often estimated via Transfer factors from Control regions (CR) to Signal region (SR). Allows for the cancellation of correlated systematics

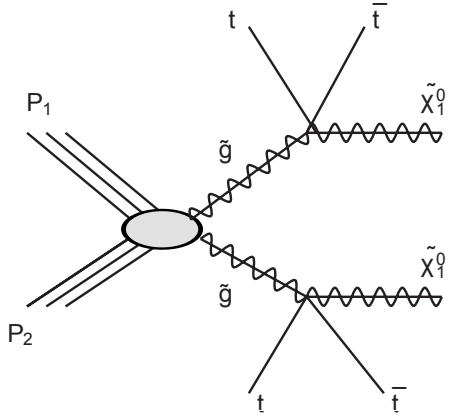
$$N_{SR}^{bkg,est} = \frac{N_{SR}^{bkg,MC}}{N_{CR}^{bkg,MC}}(N_{CR}^{data} - N_{CR}^{other,MC}) = TF(N_{CR}^{data} - N_{CR}^{other,MC}) \quad (1)$$

- Fake lepton backgrounds: Measure parametrized fake rates in multijet dominated regions, and apply them to objects that could result in fakes
- Fake E_T^{Miss} multijet backgrounds: data driven technique based on the smearing of jet energies
- Sub-dominant backgrounds estimated using Monte Carlo

Search for gluino-mediated stop pair production







1-ℓ + b-jets + m_{Eff}: ATLAS-CONF-2012-003

2-ℓ (SS): arXiv:1203.5763, submitted to PRL (ATLAS)

0-ℓ + 6-9 jets: ATLAS-CONF-2012-037

2-ℓ (SS) + b-jets: CMS-PAS-SUS-11-020

Gluino-mediated stop (ATLAS): Analyses

Search for gluino mediated stop with $\tilde{t}_1 \rightarrow t + \tilde{\chi}^0$ or $\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^{\pm}$

$\Rightarrow$ many jets, b-jets, leptons and $\not{E}_T$

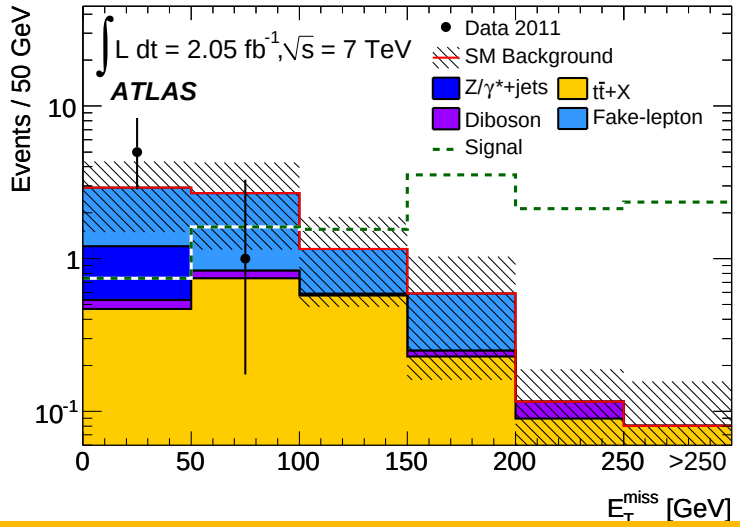
2 same-sign leptons

- $\geq$ 2 leptons (e, μ), $p_T > 20$ GeV
- 2 leading leptons: same sign
- $\geq$ 4 jets with $p_T > 50$ GeV

Two signal regions:

▷SR1: $\not{E}_T > 150$ GeV

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



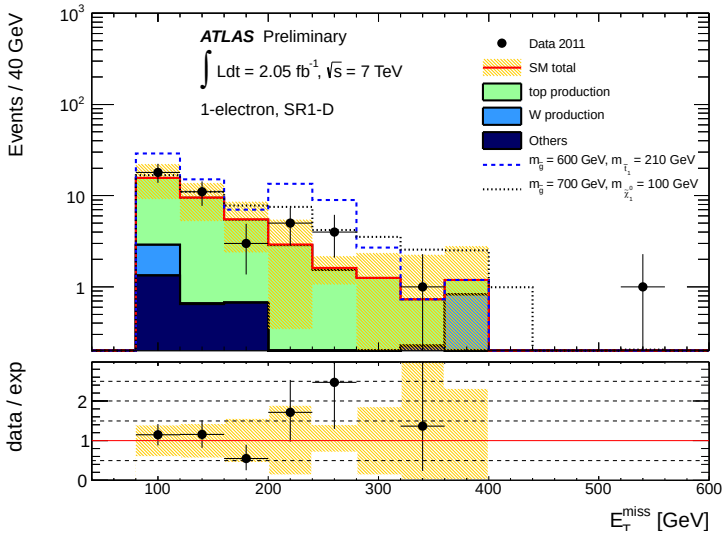
1 lepton + b-jets

- = 1 lep with $p_T > 20(e)$, $25(\mu)$ GeV
- $\geq$ 4 jets, $\geq$ 1 b-jet
- $m_T > 100$ GeV

Two signal regions:

▷SR1: $\not{E}_T > 80$ GeV, $m_{Eff} > 700$ GeV

▷SR2: $\not{E}_T > 200$ GeV, $m_{Eff} > 700$ GeV



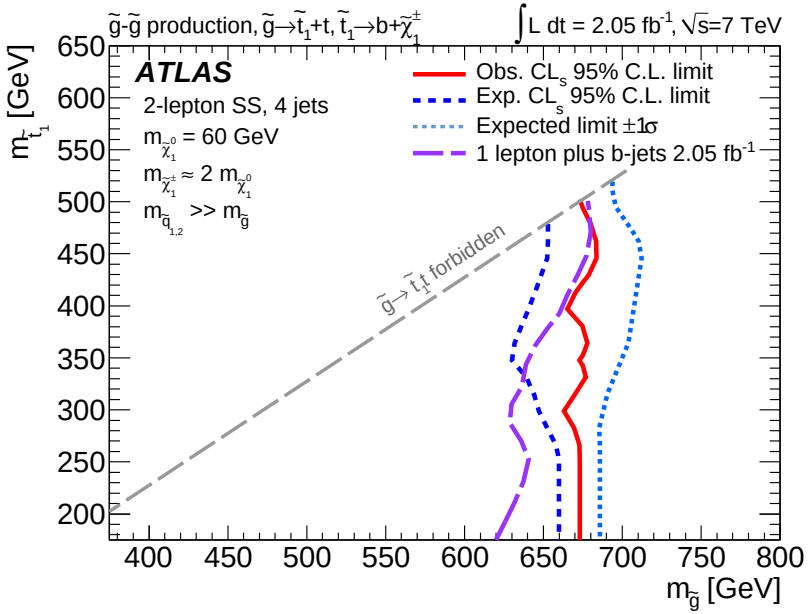
Gluino-mediated stop (ATLAS): Interpretation

Phenomological MSSM

▷Production: $\tilde{g}\tilde{g} + \tilde{t}_1\tilde{t}_1$

▷Spectrum: $m(\tilde{\chi}^0) < m(\tilde{t}_1) < m(\tilde{g})$, $m(\tilde{\chi}^0) = 60$ GeV, $m(\tilde{\chi}_1^{\pm}) \approx 2m(\tilde{\chi}^0)$

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



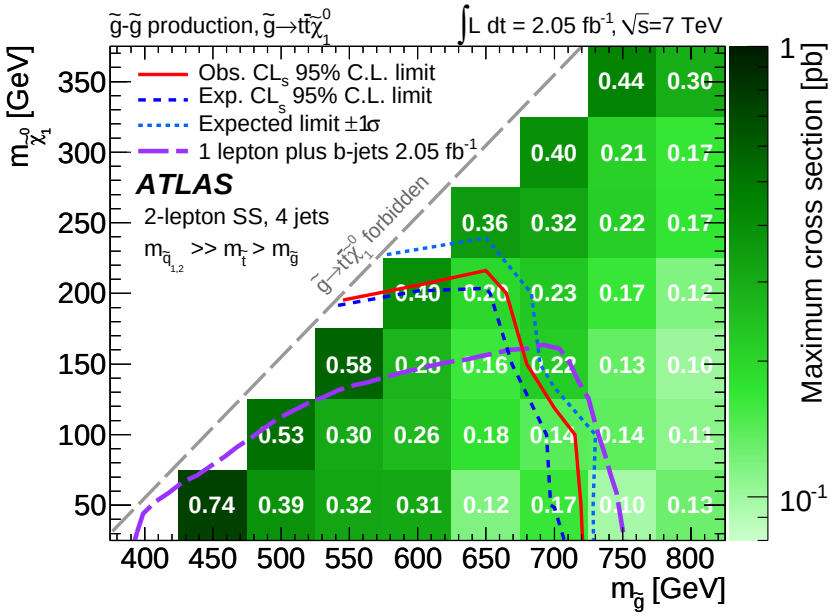
Exclude: $m(\tilde{g}) < 650$ GeV for $m(\tilde{t}_1) < 450$ GeV

Simplified Model

▷Production: $\tilde{g}\tilde{g}$

▷Spectrum: $m(\tilde{\chi}^0) < m(\tilde{g}) < m(\tilde{t}_1)$

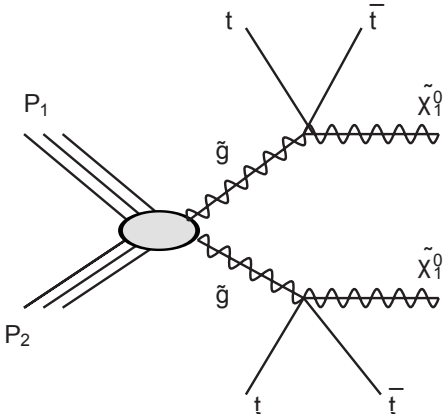
▷Decays: $\tilde{g} \to t\bar{t} + \tilde{\chi}^0$ via off shell stop

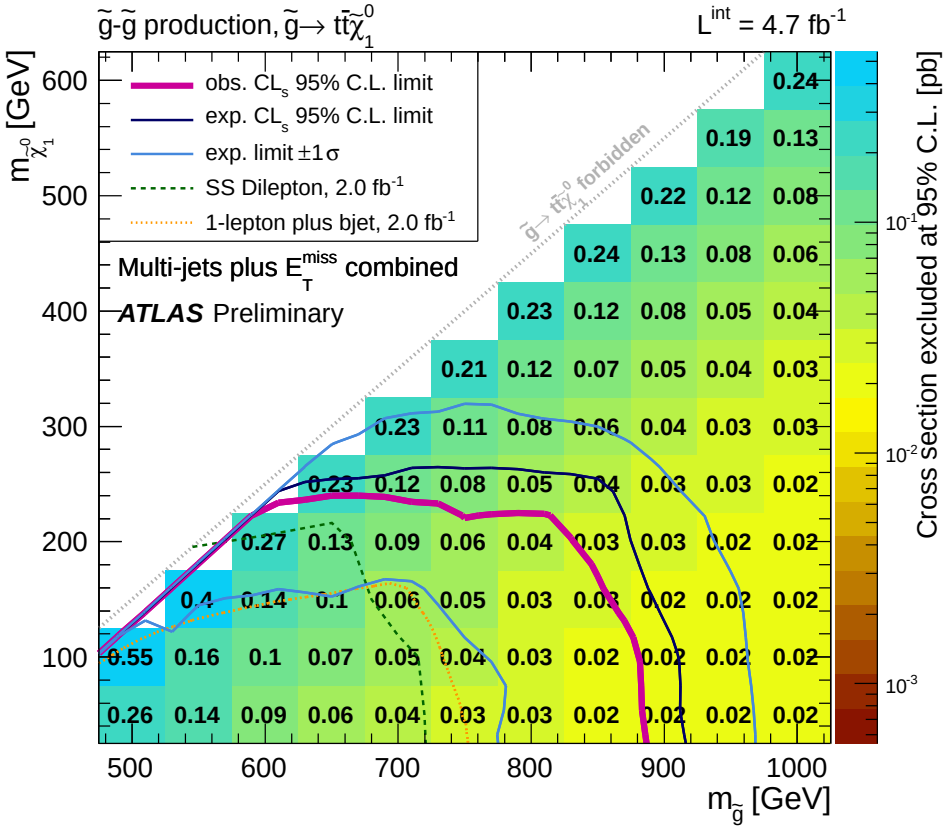


Exclude: $m(\tilde{g}) < 750$ GeV for $m(\tilde{\chi}^0) = 0$ GeV

Search for gluino-mediated stop with multijets (ATLAS)

- Details available in: ATLAS-CONF-2012-037
- Use 6-9 jets, 0-ℓ, E_T^{Miss}-significance





Search for gluino-mediated stop (CMS): Analysis

CMS use a same sign di-lepton search with 2 b-jets to search for a variety of models.
7 signal regions with different # jets, E_T^{Miss} and H_T

	SR1	SR2	SR3	SR4	SR5	SR6	SR7
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$\not{E}_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV	≥ 50 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV	≥ 320 GeV	≥ 320 GeV	≥ 200 GeV

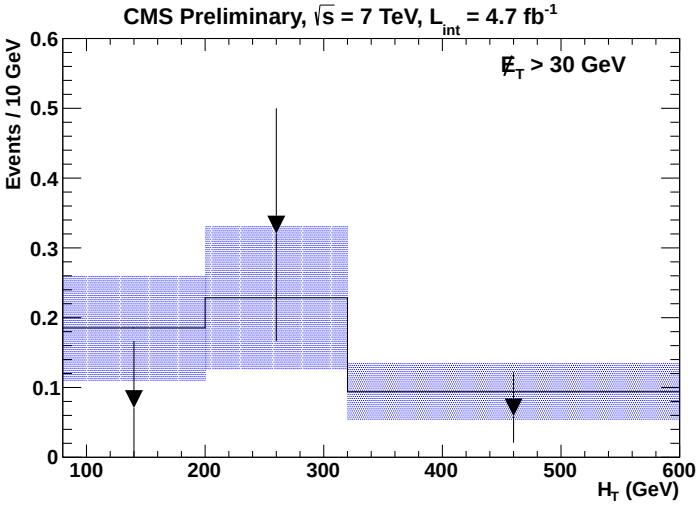
Background Estimation

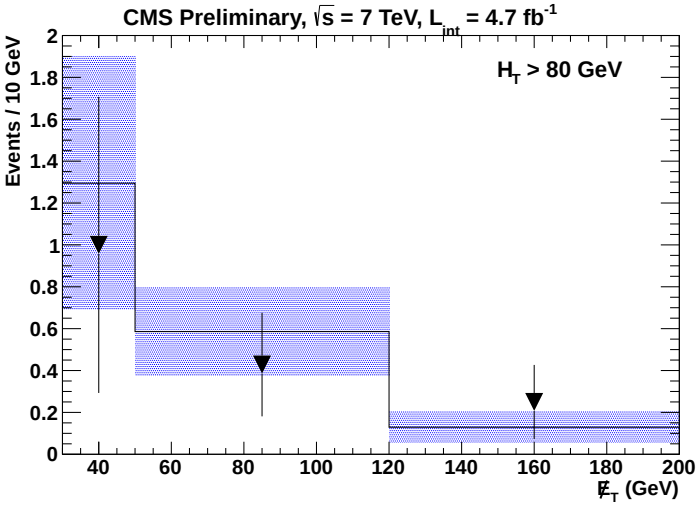
- Fake leptons: Use a CR to measure lepton fake rates, parametrized by p_T,η,p_T(parent parton), and apply these to fake-able objects at penultimate cut
- OS leptons reconstructed as SS: Parametrize charge flip probability for e ($\approx 10^{-3}$) and μ ($\approx 10^{-5}$) and use this to weight OS events
- Rare SM background: Use Monte Carlo (Madgraph)

Search for gluino-mediated stop (CMS): Results

Observations match up with Standard Model expectation:

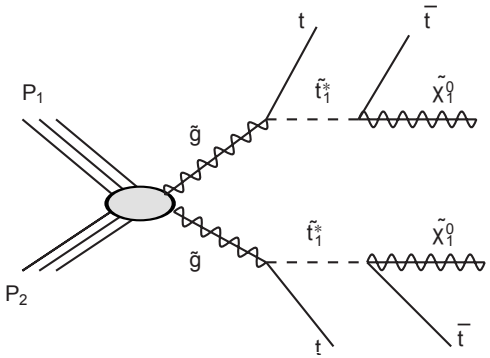
	SR1	SR2	SR3	SR4	SR5	SR6	SR7
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$\not{E}_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV	≥ 50 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV	≥ 320 GeV	≥ 320 GeV	≥ 200 GeV
q-flip BG	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.0	0.026 ± 0.009	0.008 ± 0.004
Fake BG	3.4 ± 2.0	1.8 ± 1.2	0.32 ± 0.50	1.5 ± 1.1	0.81 ± 0.7	0.15 ± 0.45	0.15 ± 0.45
Rare SM BG	3.2 ± 1.6	2.1 ± 1.1	0.56 ± 0.28	2.0 ± 1.0	1.04 ± 0.5	0.39 ± 0.20	0.11 ± 0.06
Total BG	7.7 ± 2.6	4.4 ± 1.6	0.9 ± 0.6	3.7 ± 1.5	2.0 ± 0.9	0.6 ± 0.5	0.3 ± 0.5
Event yield	7	5	2	5	2	0	0
N_{UL} (12% unc.)	7.4	6.9	5.2	7.3	4.7	2.8	2.8
N_{UL} (20% unc.)	7.7	7.2	5.4	7.6	4.8	2.8	2.8
N_{UL} (30% unc.)	8.1	7.6	5.8	8.2	5.1	2.8	2.8

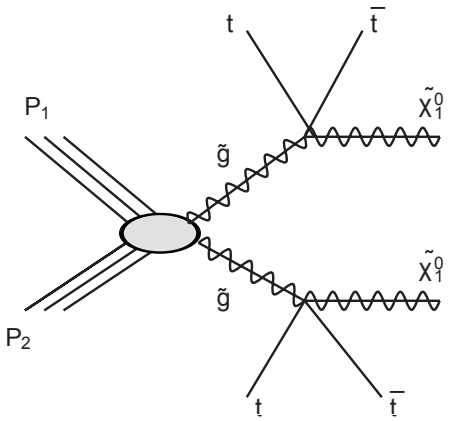


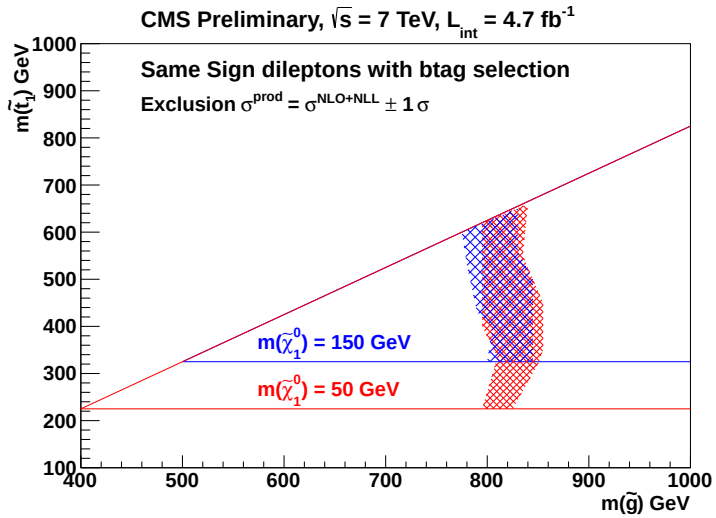


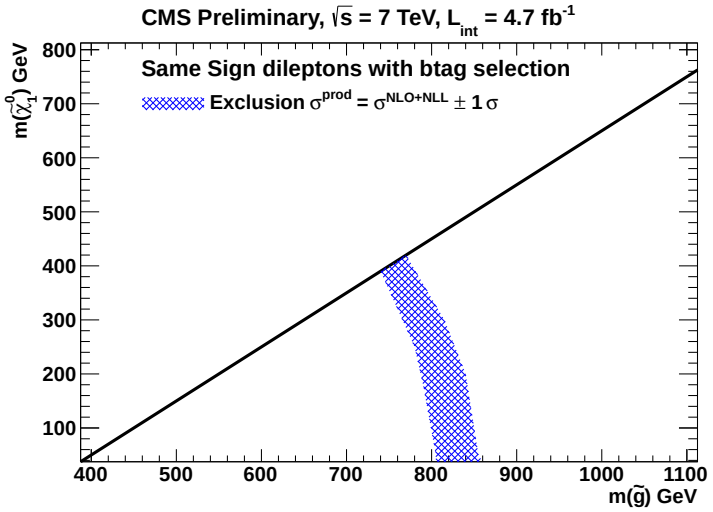
Search for gluino-mediated stop (CMS): Interpretation

Interpret in a gluino-mediated stop scenario with on-shell (left) or off-shell stops (right)

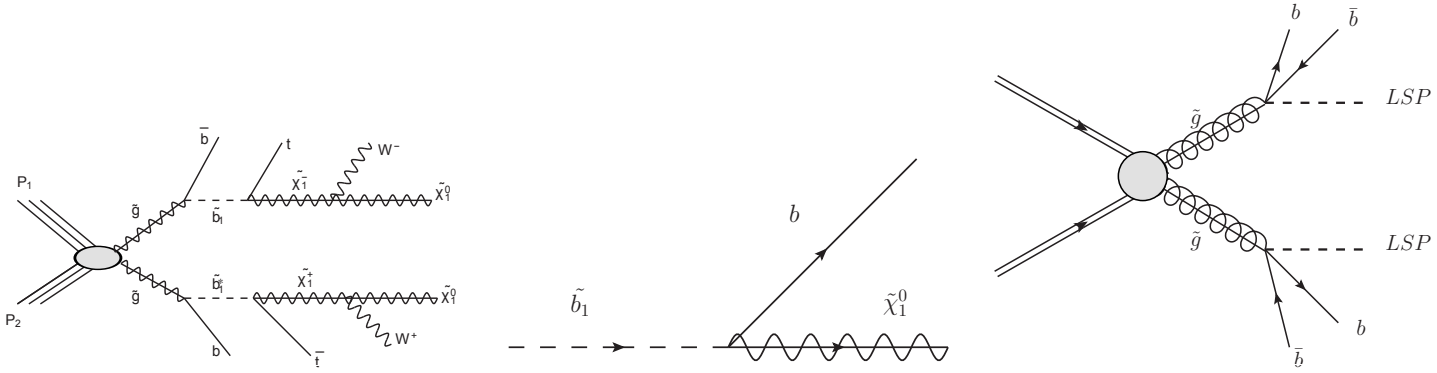








Search for gluino-mediated sbottom pair production



0-ℓ + b-jets + m_{Eff}: ATLAS-CONF-2012-003

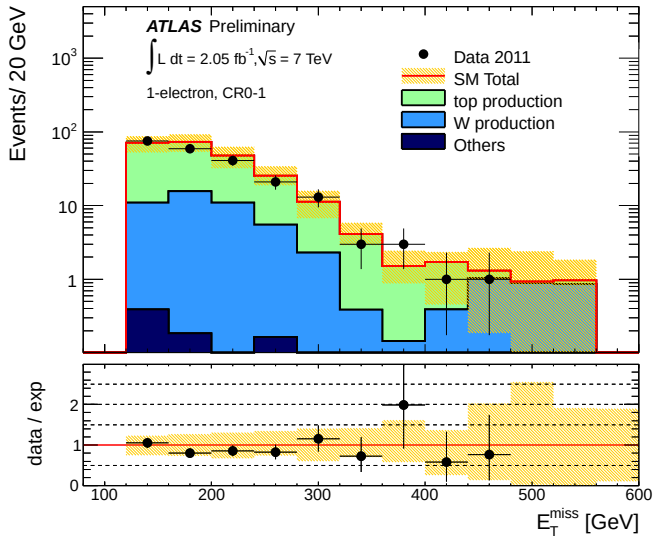
2-ℓ + b-jets :CMS-PAS-SUS-11-020

Gluino-mediated Sbottom (ATLAS): Analysis

Signal is busy: 4 b-jets and 2 $\tilde{\chi}^0 \Rightarrow b$-jets $+ E_T^{Miss}$ so use m_{Eff}

Selection cuts: 0 lepton

- MET + jet trigger fully efficient:
  - 3 jets $p_T > 130, 50, 50$ GeV
  - $E_T^{Miss} > 130$ GeV
- QCD Rejection: E_T^{Miss}/M_{Eff} and $\Delta\phi_{\min}(E_T^{Miss}, \text{jets}_{1-3})$
- Enhance SUSY signal:
  - ≥ 1 b-jet and ≥ 2 b-jets
  - $M_{Eff} > 500/700/900$ GeV



Control region for $t\bar{t}$ + WHF.

Top, WHF Background: Use TF with 1 lepton Control Region (CR)
Other backgrounds estimated using data driven techniques (multijets) or MC (other backgrounds)

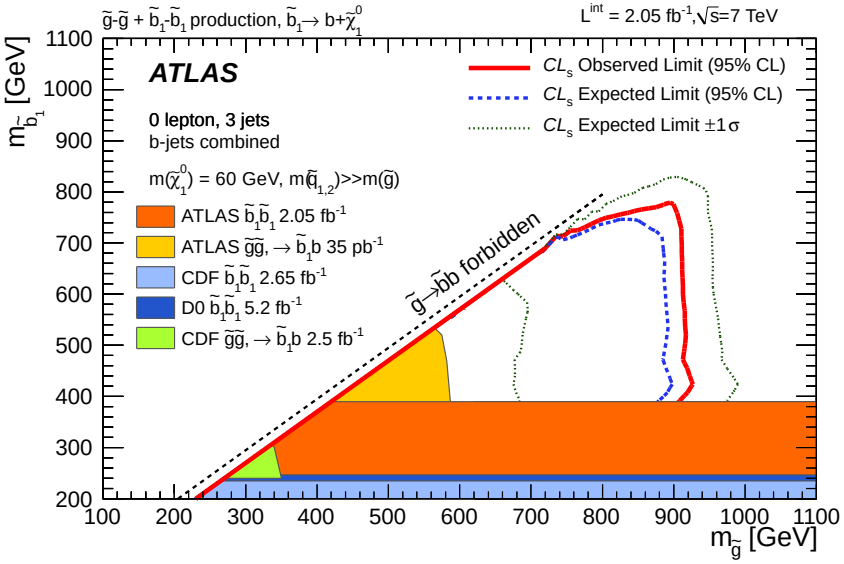
Gluino-mediated Sbottom (ATLAS): Interpretation

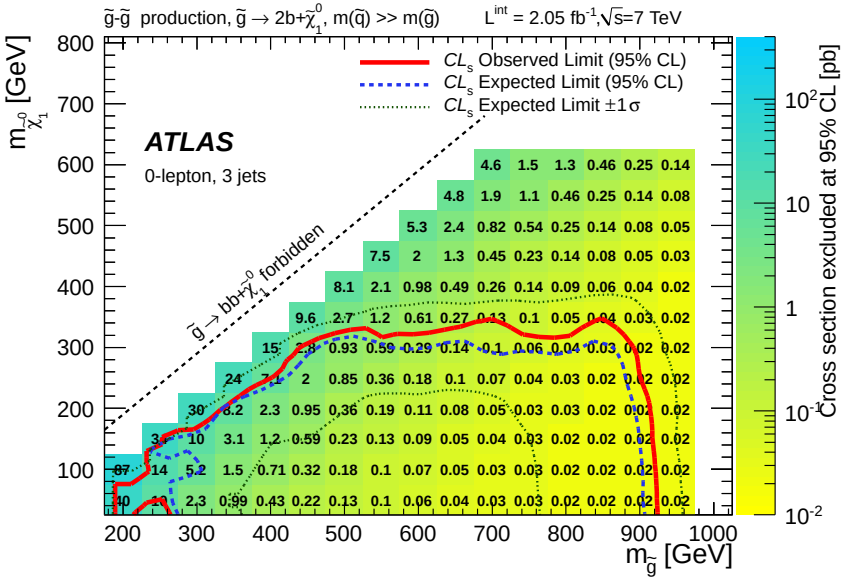
No excess so we set 95 % C.L. Upper Limits

Interpretation dependent on mass spectrum

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

- $m(\chi) < m(\tilde{g}) < m(\tilde{b})$
- $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}^0$ via virtual $\tilde{b}$
- Exclude: $m(\tilde{g}) < 900$ GeV for $m(\tilde{\chi}^0) < 300$ GeV





Gluino-mediated Sbottom (CMS 2-ℓ)

Using the SS 2-ℓ analysis described earlier CMS interprets in a scenario where $\tilde{b}_1 \to t\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm} \to W\tilde{\chi}^0$

Final States: $\tilde{\chi}^0\tilde{\chi}^0$ and ≥ 1 b with:

- ttW^-W^-
- OR $t\bar{t}W^+W^-$
- OR $\bar{t}\bar{t}W^+W^+$

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No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
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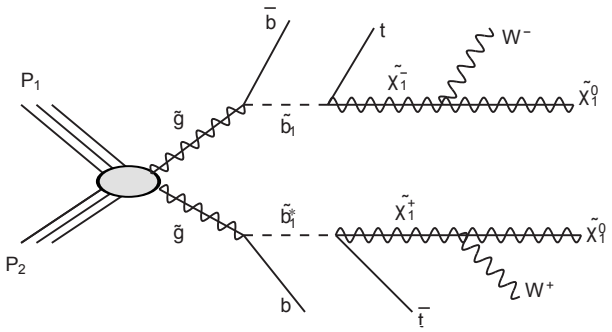
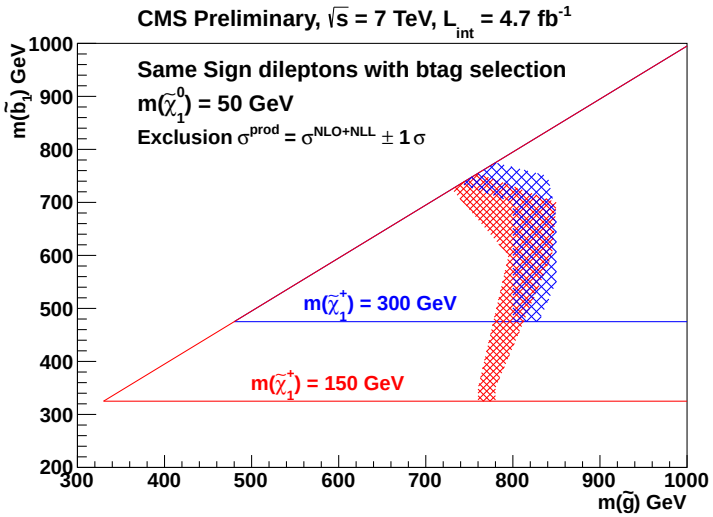




Search for direct stop pair production (GMSB)

b-jets $+ E_T^{Miss} + Z(\rightarrow \ell\ell)$: ATLAS-CONF-2012-036

Stop Pair in GMSB Search (ATLAS): Analysis

GMSB scenario with gravitino LSP ($m(\tilde{G}) < 1$ keV), $\tilde{\chi}^0$ NLSP (Higgsino-like $\tilde{\chi}^0$ considered) with $\tilde{\chi}^0 \to Z\tilde{G}$ or $\tilde{\chi}^0 \to h\tilde{G}$

Signature

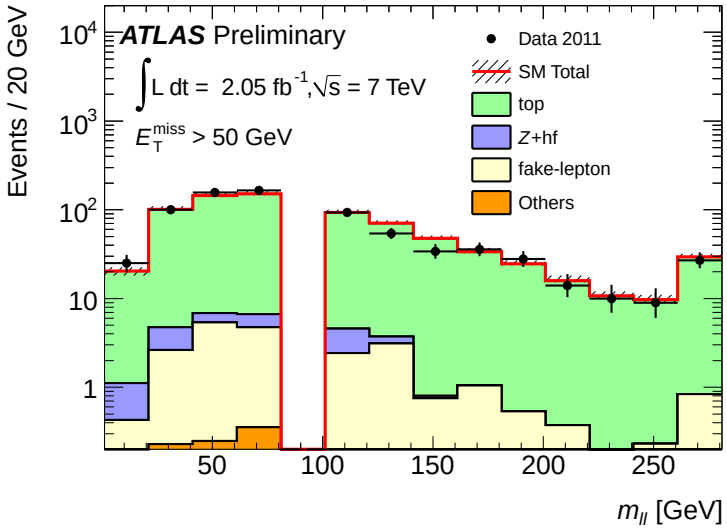
In considered scenarios: BR($\tilde{\chi}^0 \to Z\tilde{G}$) varies between 1 and 0.65 for $m(\tilde{\chi}^0)$ between 100 and 350 GeV $\Rightarrow$ 2 same-flavour ℓ + jets + E_T^{Miss}

Selection:

- 2 same flavour lep (ee or $\mu\mu$)
- 2 jets, $p_T > 60$ GeV, 50 GeV, ≥ 1 b-jet
- $86 < m(ll) < 96$ GeV
- $E_T^{Miss} > 50$ (80) GeV

Background estimates via CRs:

- Top: revert Z window
- Zbb: $E_T^{miss} < 50$ GeV

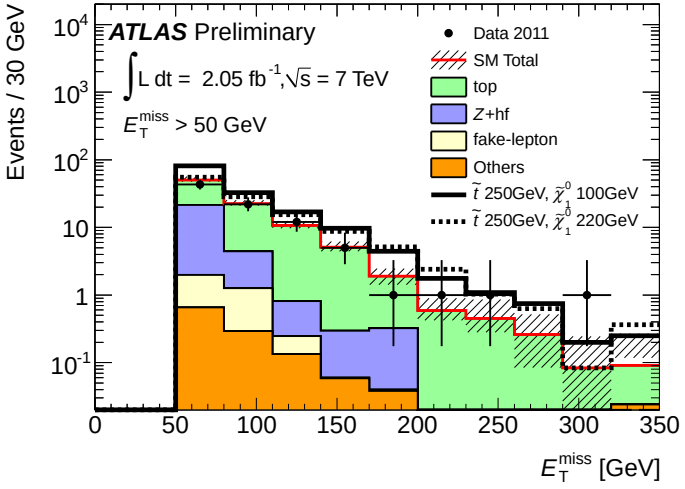


Top Control Region

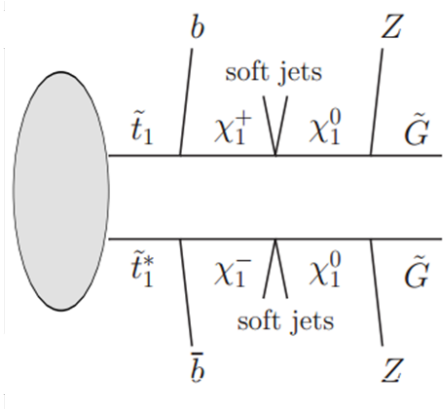
Stop Pair in GMSB Search (ATLAS): Interpretation

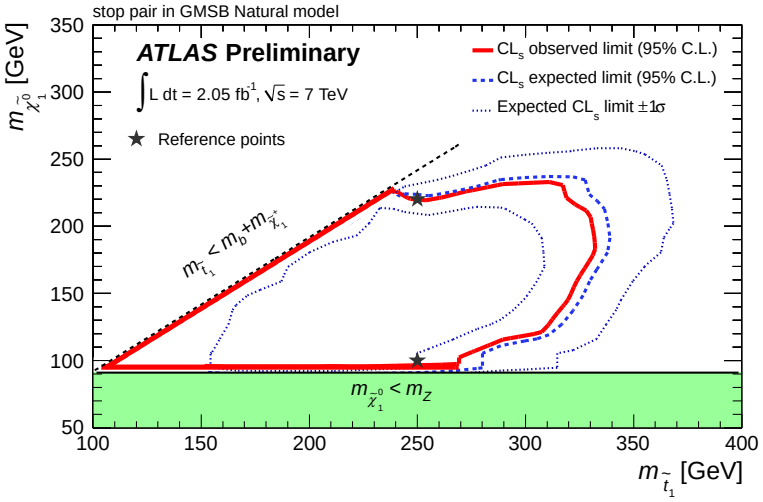
Good agreement with Standard Model expectation

	$E_T^{Miss} > 50$ GeV	$E_T^{Miss} > 80$ GeV
	$ee+\mu\mu$	
Data (2.05 fb^{-1})	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

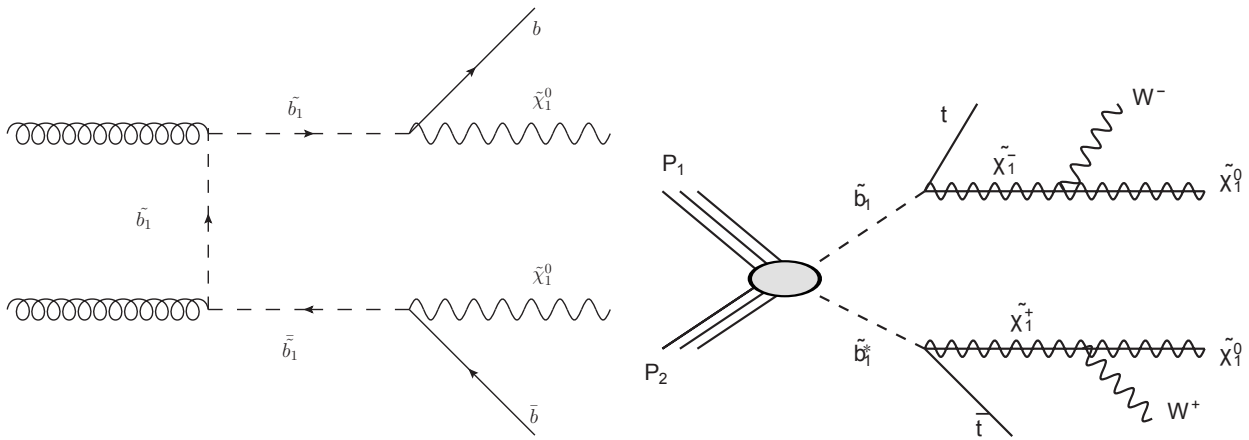


Interpretation in GMSB natural scenarios with $\tilde{G}$ LSP and $\tilde{\chi}^0$ NLSP:





Search for direct sbottom pair production



0-ℓ + b-jets + m_{CT}: arXiv :1112.3832, accepted by PRL (ATLAS)
2-ℓ + b-jets :CMS-PAS-SUS-11-020

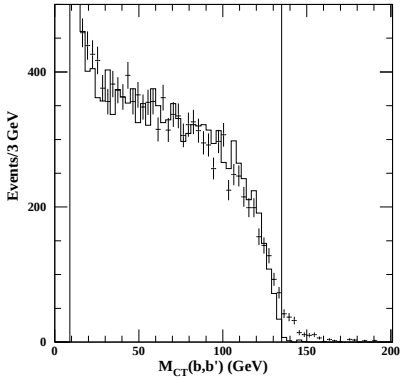
Search for Sbottom-Pair (ATLAS): Analysis

Contransverse Mass

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

- $\tilde{b}_1\tilde{b}_1$ events: Endpoint at $\frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)}$
- $t\bar{t}$ events: Endpoint at $\approx$ 135 GeV

$t\bar{t}$ $m_{CT}(b, b)$ from JHEP 1003:030,2010:

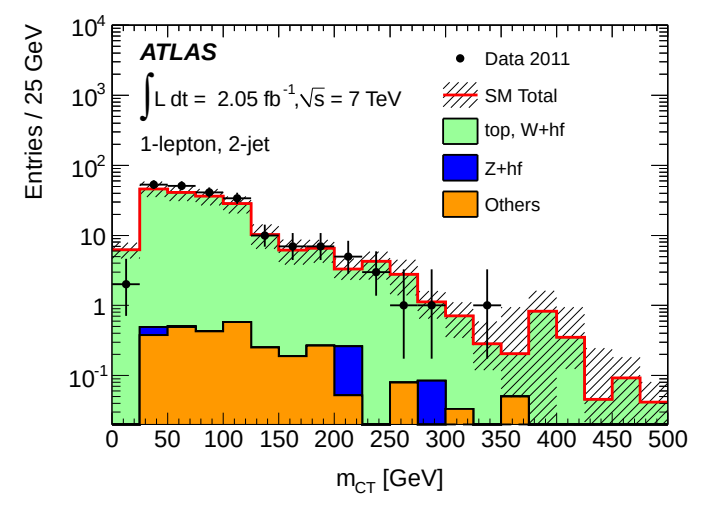


Selection cuts: 0 lepton ($p_T > 20$ GeV)

- MET + jet trigger fully efficient:
  - Exactly 2 jets with $p_T > 130$ GeV and $p_T > 50$ GeV
  - $E_T^{Miss} > 130$ GeV
- QCD Rejection: E_T^{Miss}/M_{Eff} and $\Delta\phi_{\min}(E_T^{Miss}, \text{jets})$
- Enhance S/B: 2 b-jets and $m_{CT} > 100/150/200$ GeV

Top + Wbb CR

CR: 1 lepton + E_T^{Miss} + 2 b-jets



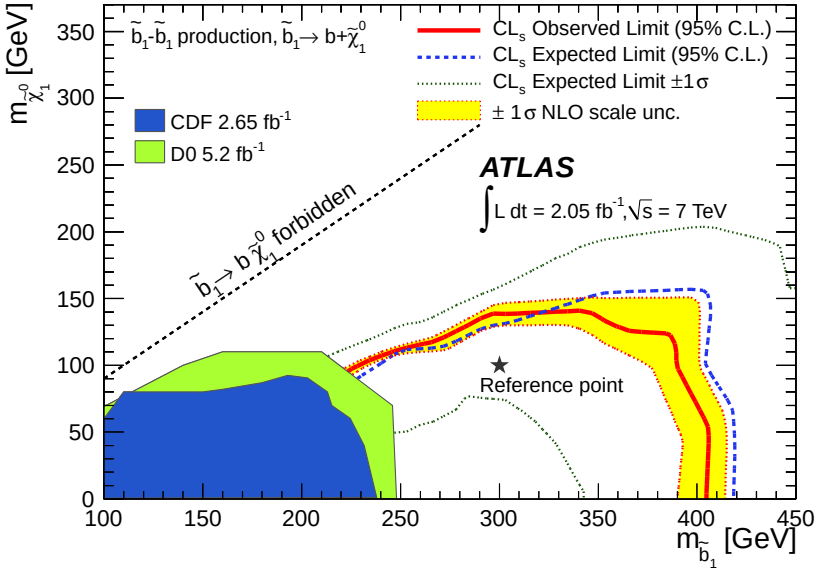
Search for Sbottom-Pair (ATLAS): Interpretation

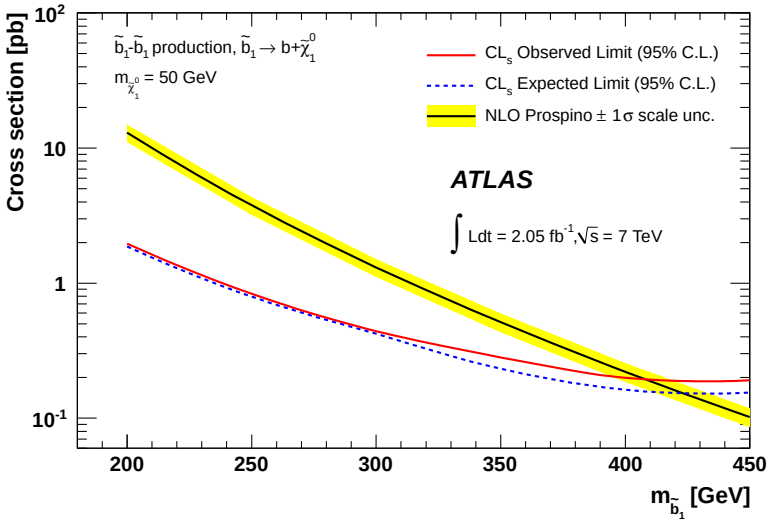
m_{CT} (GeV)	top, Wbb	Zbb	Others	Total SM	Data
0	67 ± 10	23 ± 8	3.6 ± 1.5	94 ± 16	96
100	36 ± 10	23 ± 9	3.1 ± 1.6	62 ± 13	56
150	12 ± 5	12 ± 6	2.7 ± 0.9	27 ± 8	28
200	3.2± 1.6	3.9± 3.2	1.0 ± 0.9	8.1± 3.5	10

In phenomenological MSSM:

- $\tilde{g}$ mass set very high
- $\tilde{b} \rightarrow b\tilde{\chi}^0$ with 100%

$m(\tilde{b}_1) < 390$ GeV excluded for $m(\tilde{\chi}^0) < 60$ GeV



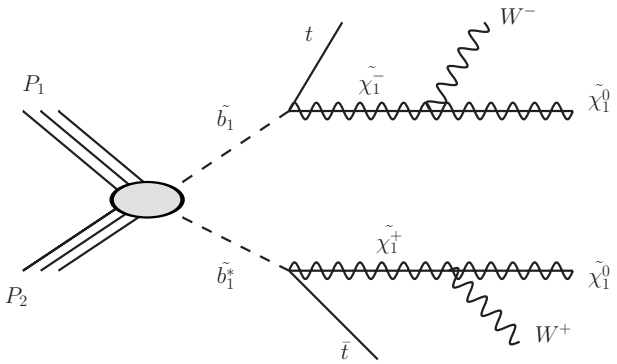


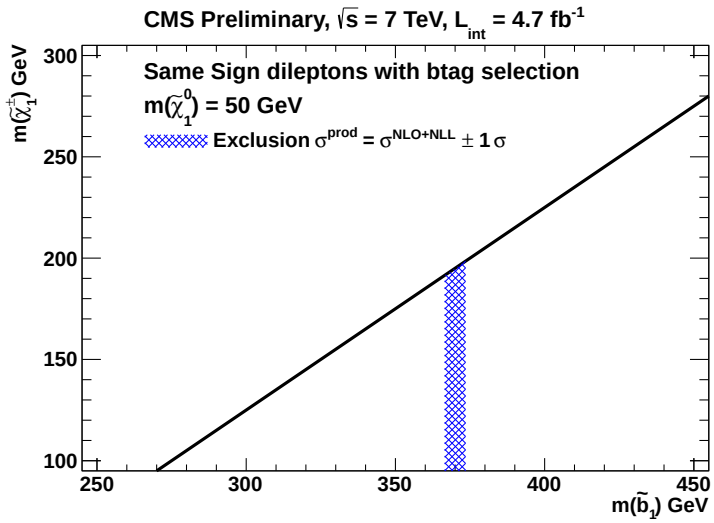
Search for Sbottom Pair (CMS)

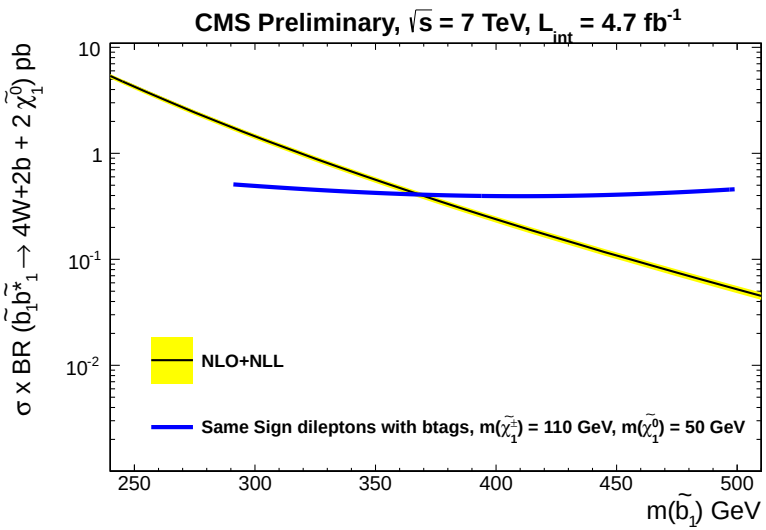
- Use SS di-lepton analysis.
- Limit from SRs with softer E_T^{Miss} important

$\tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm} \rightarrow W\tilde{\chi}^0$ resulting in a final state containing: $t\bar{t}W^+W^-$

	SR1	SR2	SR3	SR4
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2
Lepton charges	$++/--$	$++$	$++/--$	$++/--$
$\not{E}_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV
q-flip BG	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1
Fake BG	3.4 ± 2.0	1.8 ± 1.2	0.32 ± 0.50	1.5 ± 1.1
Rare SM BG	3.2 ± 1.6	2.1 ± 1.1	0.56 ± 0.28	2.0 ± 1.0
Total BG	7.7 ± 2.6	4.4 ± 1.6	0.9 ± 0.6	3.7 ± 1.5
Event yield	7	5	2	5
N_{UL} (12% unc.)	7.4	6.9	5.2	7.3
N_{UL} (20% unc.)	7.7	7.2	5.4	7.6
N_{UL} (30% unc.)	8.1	7.6	5.8	8.2







Conclusions and outlook

- Strong interest in third generation searches
- Wide array of third generation searches for SUSY at ATLAS and CMS
  - $\tilde{g}/\tilde{q}$-mediated stau
  - $\tilde{g}$-mediated stop
  - $\tilde{g}$-mediated sbottom
  - direct stop pair (GMSB)
  - direct sbottom pair

Outlook

- Took a good bite out of the SUSY parameter space ☹
- More 5 fb^{-1} results to follow
- Both experiments looking forward to 8 TeV data coming in 2012! ☺

BACKUP SLIDES

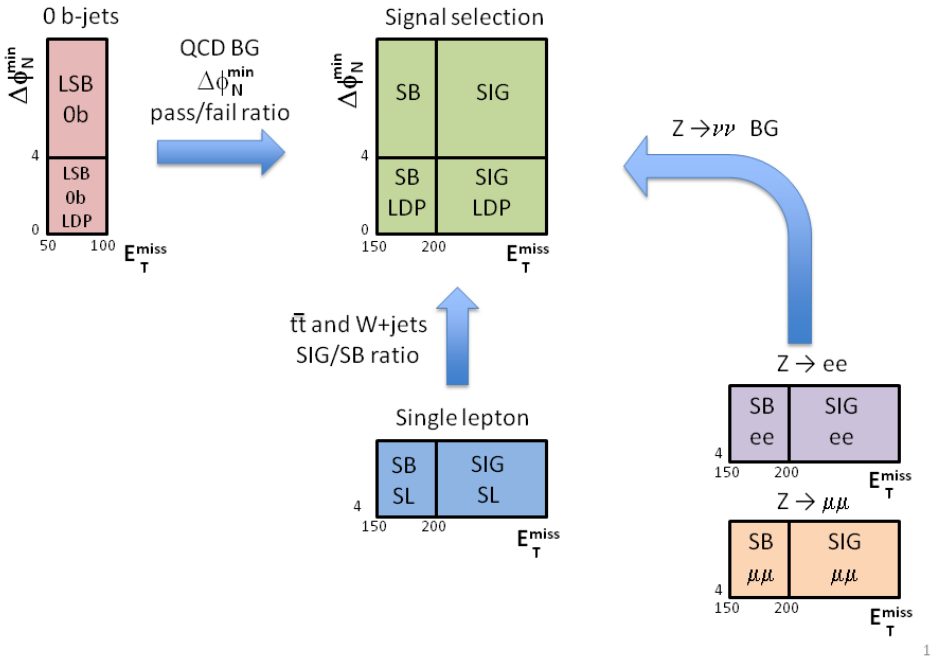
Gluino-mediated Sbottom (CMS 0-ℓ): Analysis

Analysis described in full : CMS-PAS-SUS-11-006

Data driven background estimate:

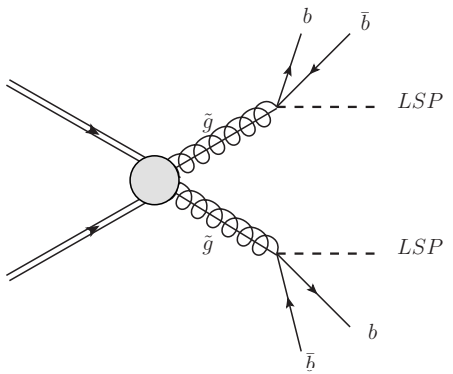
Selection cuts

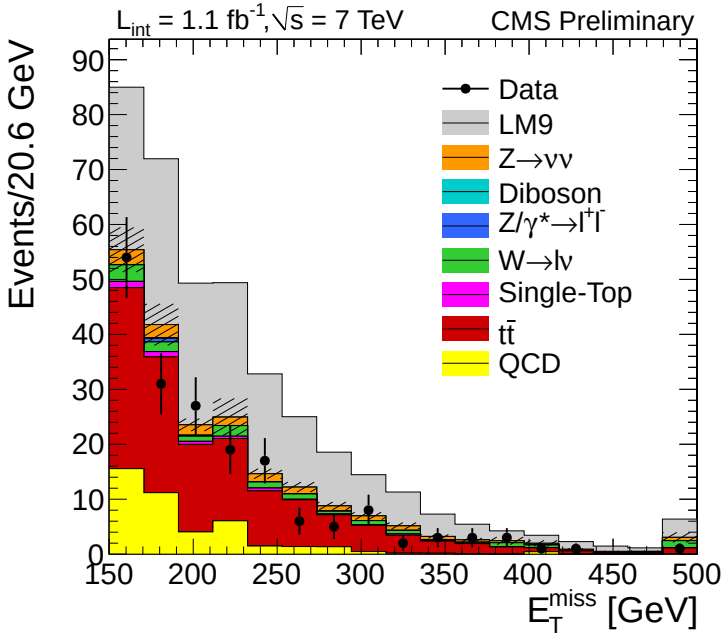
- 3 $p_T > 50$ GeV jets
- ≥ 1 b-jet
- $\Delta\Phi^N_{Min} > 4$
- $H_T > 350$ (500) GeV
- $E_T^{Miss} > 200$ (300) GeV

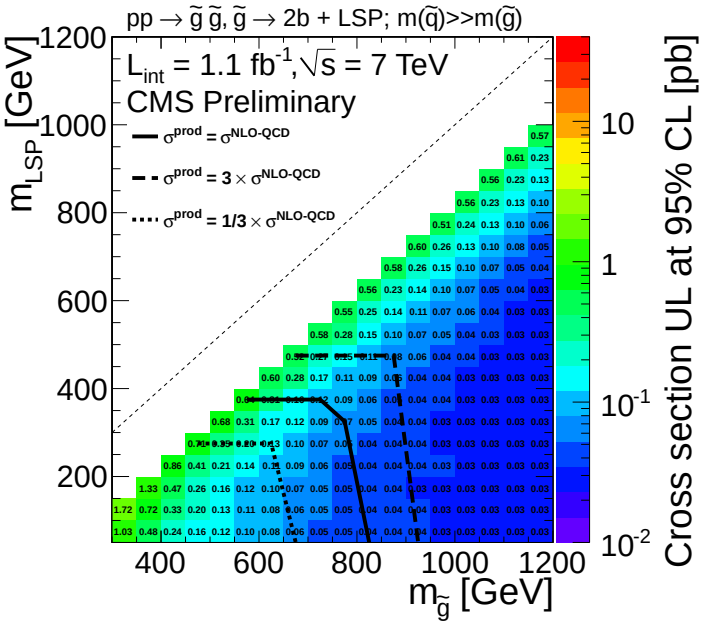


Gluino-mediated Sbottom (CMS 0-ℓ): Interpretation

- $m(\chi) < m(\tilde{g}) < m(\tilde{b})$
- $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}^0$ via virtual $\tilde{b}$
- Exclude: $m(\tilde{g}) < 900$ GeV for $m(\tilde{\chi}^0) < 300$ GeV







Backup: Search for $\tilde{g}/\tilde{q}$-mediated stau production

$1\ \tau + E_T^{Miss}$ analysis: ATLAS-CONF-2012-005

$2\ \tau + E_T^{Miss}$ analysis: ATLAS-CONF-2012-002

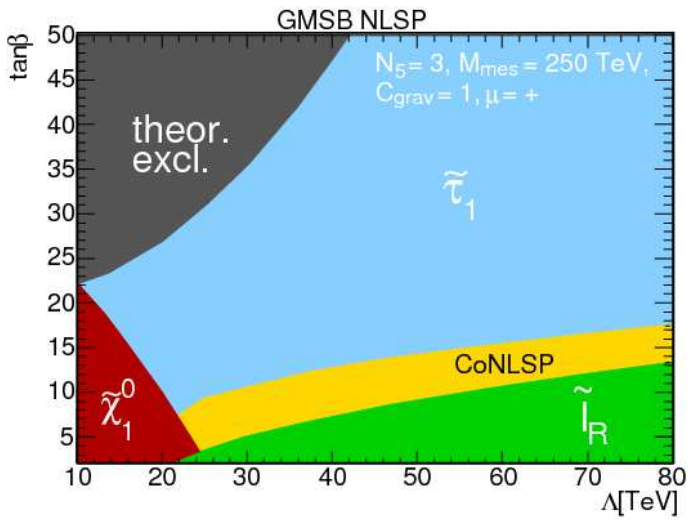
Backup: $\tilde{g}$ or $\tilde{q}$ mediated $\tilde{\tau}_1$ (ATLAS): Analysis

Search for $\tilde{\tau}_1$ production within Gauge Mediated SUSY Breaking (GMSB)

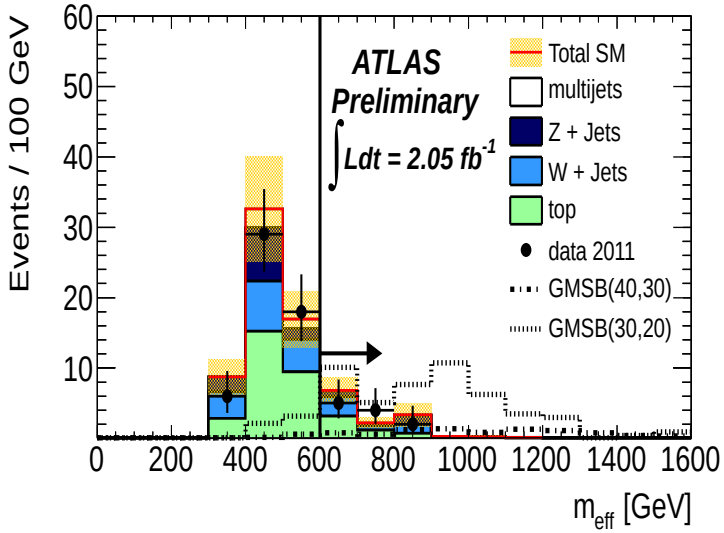
- Large mixing of $\tilde{\tau}_L$ and $\tilde{\tau}_R \Rightarrow$ low $\tilde{\tau}_1$, often the NLSP in GMSB

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

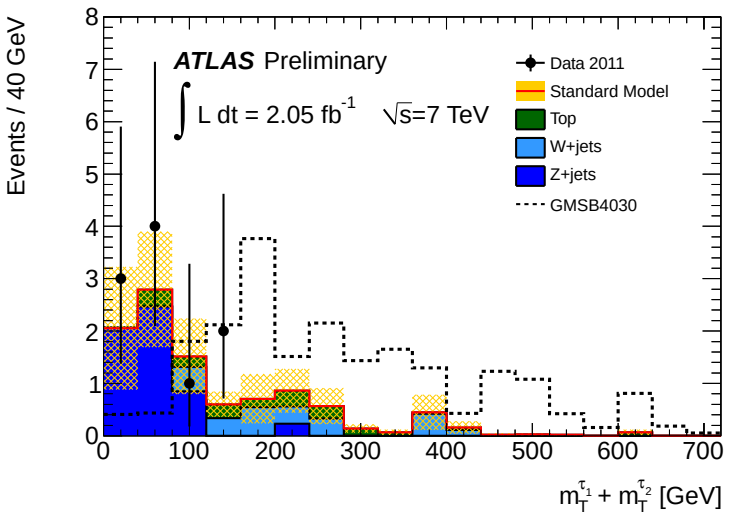
- jet+E_T^{Miss} trigger, $p_T(j_1), E_T^{Miss} > 130$ GeV
- ≥ 2 jets, $p_T > 30$ GeV



≥ 1 tight hadronic tau ($p_T > 20$GeV), $m_T(\tau) > 110$ GeV, $m_{Eff} > 600$ GeV



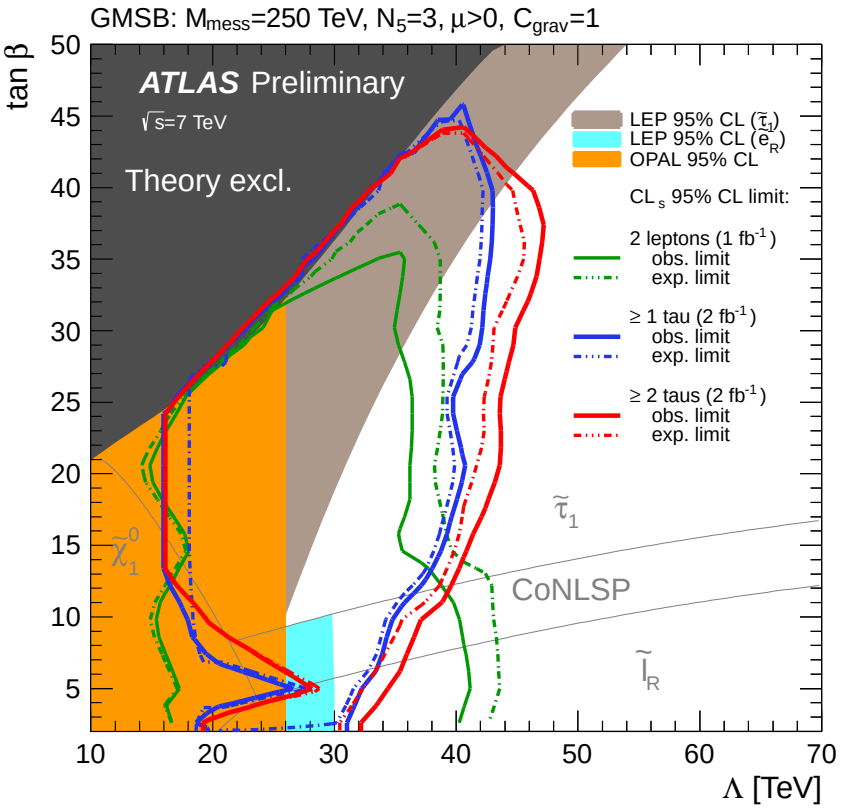
≥ 2 loose hadronic taus ($p_T > 20$GeV) $m_T(\tau_1) + m_T(\tau_2) > 80$GeV, $m_{Eff} > 700$GeV



Backup: $\tilde{g}$ or $\tilde{q}$ mediated $\tilde{\tau}_1$ (ATLAS): Interpetation

GMSB interpretation of results in the following hypothesis:

- $M_{Mess} = 250$ 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, $\tilde{G}$ (O keV)
- Variety of possible NLSP ($\tilde{\nu}, \tilde{\tau}_1, \tilde{\ell}_R, \tilde{\chi}^0$) but mostly $\tilde{\tau}_1$ at large $\tan\beta$



1 τ analysis: Exclude $\Lambda < 40$ TeV for $\tan\beta > 15$

2 τ analysis: (Best) exclusion of $\Lambda < 47$ TeV for $\tan\beta = 37$

Backup: Multijets Analysis (ATLAS)

Details available in: ATLAS-CONF-2012-037

Signal region	**7j55**	**8j55**	**9j55**	**6j80**	**7j80**	**8j80**
Multi-jets	91±20	10±3	1.2±0.4	67±12	5.4±1.7	0.42±0.16
$t\bar{t} \to q\ell, \ell\ell$	55±18	5.7±6.0	0.70±0.72	24±13	2.8±1.8	0.38±0.40
W + jets	18±11	0.81±0.72	0+0.13	13±10	0.34±0.21	0+0.06
Z + jets	2.7±1.6	0.05±0.19	0+0.12	2.7±2.9	0.10±0.17	0+0.13
Total Standard Model	**167±34**	**17±7**	**1.9±0.8**	**107±21**	**8.6±2.5**	**0.80±0.45**
Data	**154**	**22**	**3**	**106**	**15**	**1**

Table: Results for each of the six signal regions for an integrated luminosity of 4.7 fb^{-1}.

Backup: CMS SS Analysis Details

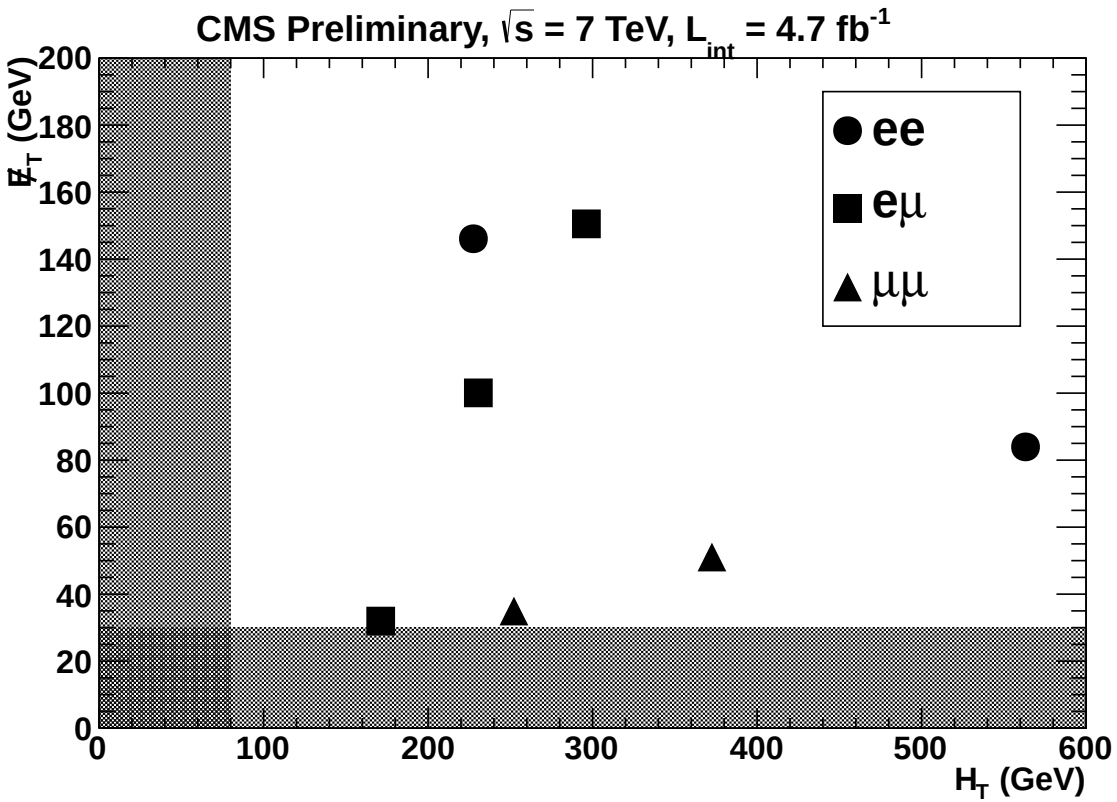
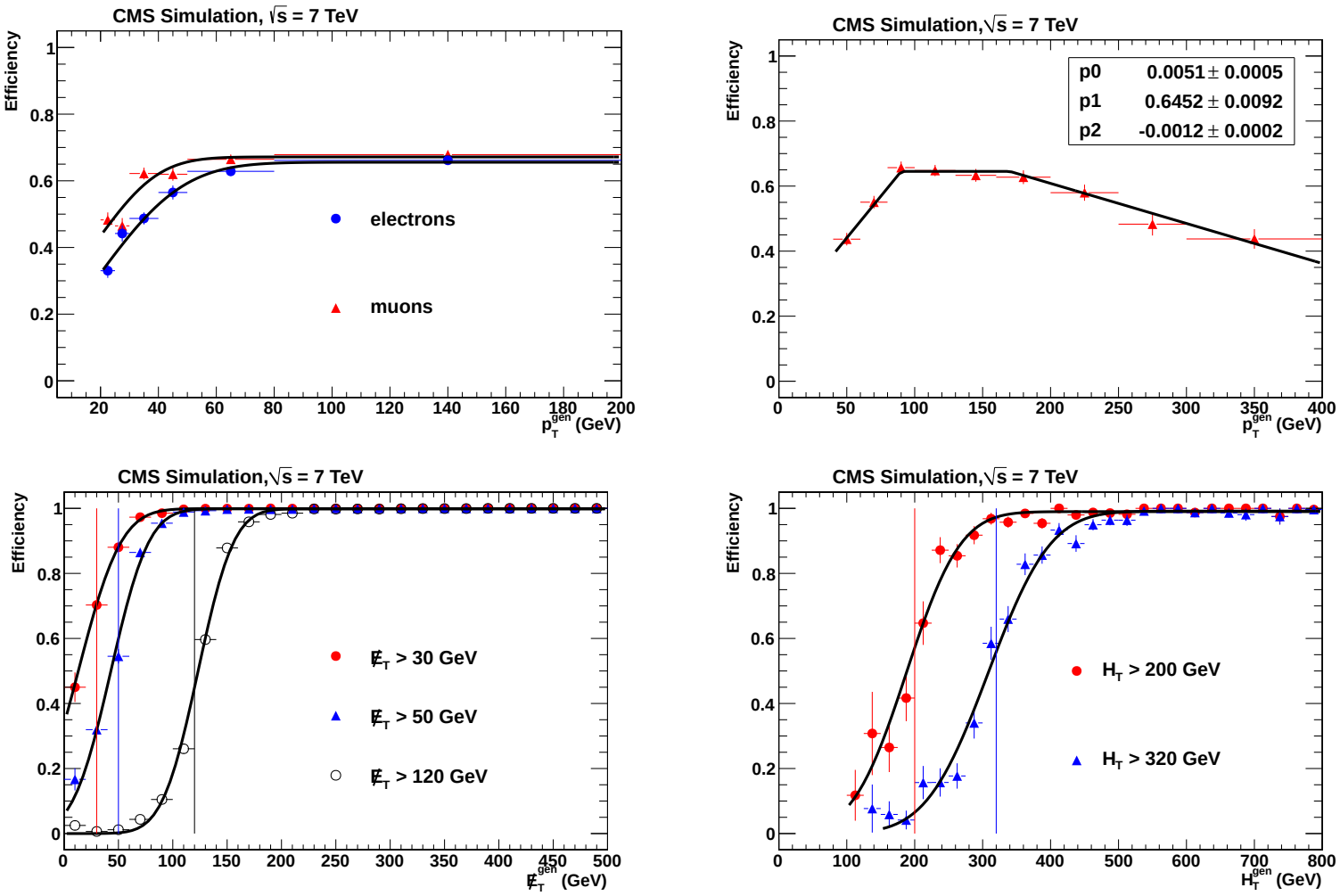


Figure: Distribution of ET vs. HT for the seven events in SR1; ee events: circles; eμ events: squares; $\mu\mu$ events: triangles

Backup: (CMS) Information on Model Building

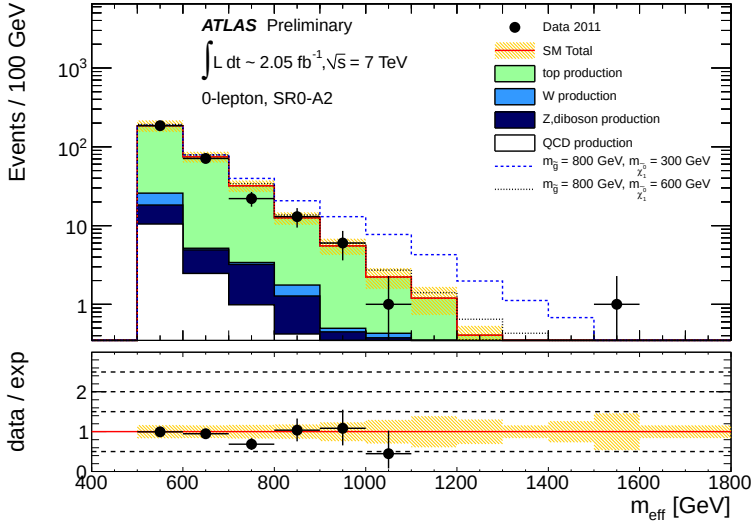
Efficiencies of selection cuts in terms of generated quantities

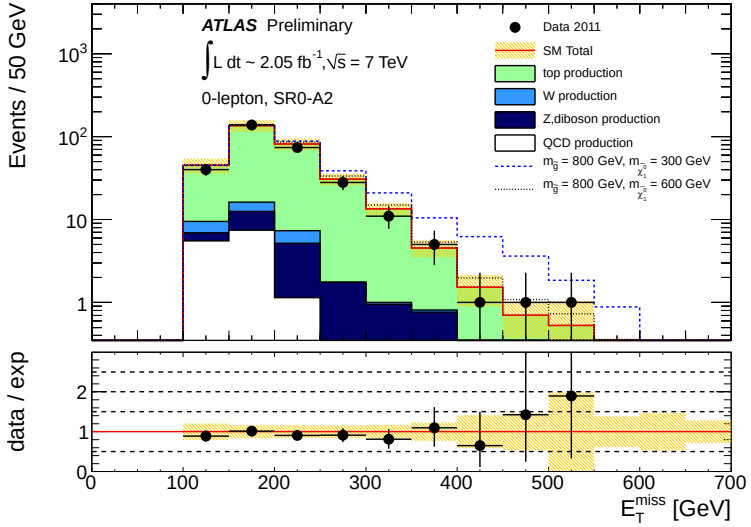


Gluino-mediated Sbottom (ATLAS): Analysis

Theory uncertainties in the transfer factor dominate background systematics.

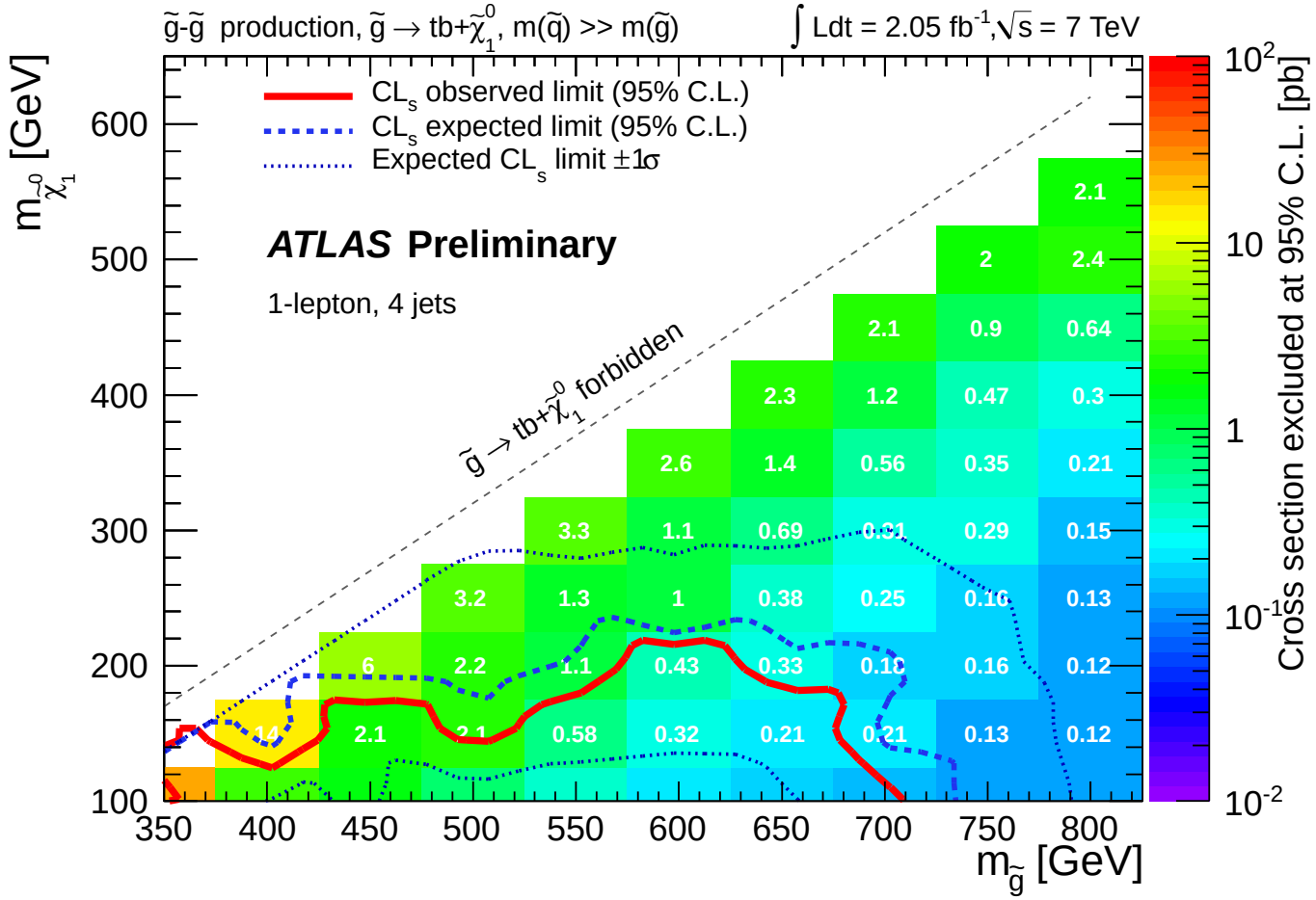
# b	m_{Eff} >	Top	W/Z	Other	Total	Data
≥ 1	500 GeV	705	248	53	1000 ± 180	1112
≥ 1	700 GeV	119	67	7.3	190 ± 50	197
≥ 1	900 GeV	22	16	1.5	39 ± 14	34
≥ 2	500 GeV	272	22.5	21	316 ± 72	299
≥ 2	700 GeV	47	4.5	2.8	54 ± 11	43
≥ 2	900 GeV	8.5	0.8	0.5	9.8 ± 3.2	8





Search for gluino-mediated stop/sbottom (ATLAS)

- Details are available in: ATLAS-CONF-2012-003
- Use 1-ℓ + b-jets + m_{EFf} analysis



Search for Sbottom-Pair (ATLAS): Results

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.