Search for supersymmetry in final states with b-jets and missing transverse energy with the ATLAS detector

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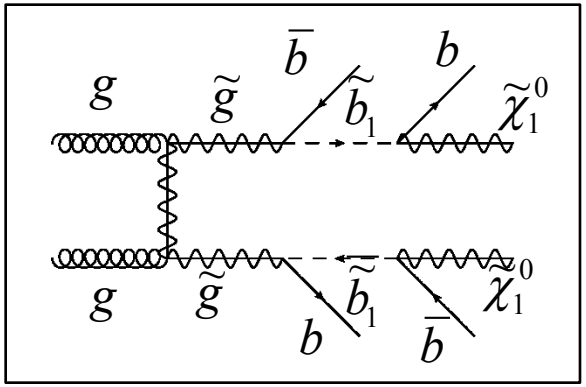
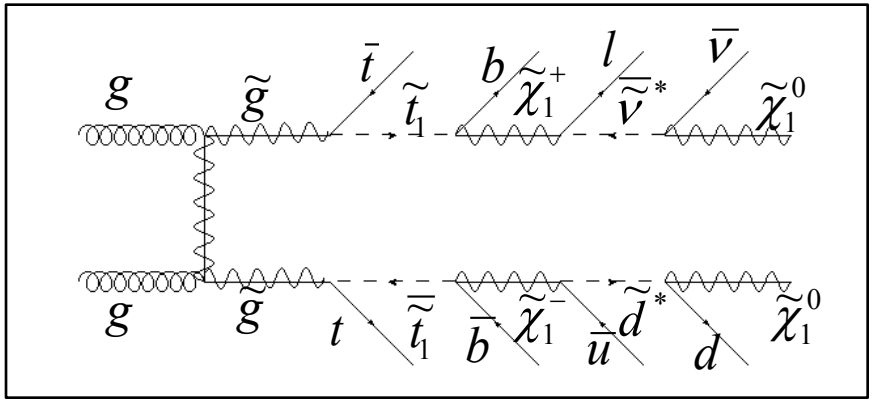
Introduction

- Supersymmetry (SUSY) is one of the most compelling theories to describe physics beyond the Standard Model (SM).
  - *R*-parity conserving scenarios lead to signatures with unbalanced energy + jets / leptons.
  - Third generation scalar fermions can be lighter and stop and sbottom produced either via direct production or gluino decays.

→ **Final states involving *b*-jets**



~g→b~b_1 decay diagram



~g→ t ~t_1 decay diagram

Analysis Strategy

- Two searches are presented.
  - lepton veto, 3-jet (1 or 2 *b*-jet) for sbottom search using 0.83 fb^{-1} data
    - ATLAS Collaboration, ATLAS-CONF-2011-098 (2011).
  - 1-lepton, 4-jet (1 *b*-jet) for stop search using 1.03 fb^{-1} data
    - ATLAS Collaboration, ATLAS-CONF-2011-130 (2011).
- This is the update of analysis at 2010, integrated luminosity of 35 pb^{-1}.
  - ATLAS Collaboration, "Search for supersymmetry in *pp* collisions at sqrt(s)=7 TeV in final states with missing transverse momentum and *b*-jets", Physics Letters B Volume 701, Issue 4, July 2011, p.398-416

Object Definition (I)

- jet :
  - reconstructed from anti-k_t jet clustering algorithm,
  - distance parameter R=0.4, $|\eta| < 2.8$, $p_T > 20$ GeV
- *b*-tagged jet :
  - $p_T > 50$ GeV
  - secondary vertex-based tagger with 50% *b*-tagging efficiency (light jet rejection rate ~270) for 0-lepton channel
  - secondary vertex / impact parameter combined tagger with 60% *b*-tagging efficiency (light jet rejection rate ~350) for 1-lepton channel
- electron :
  - *medium* ID, $p_T > 20$ GeV, $|\eta|<2.47$, d$R > 0.4$ from jets
- muon :
  - inner detector / muon spectrometer combined, track quality, $p_T > 10$ GeV, $|\eta|<2.47$, d$R > 0.4$ from jets

Object Definition (II)

- E_T^{miss} : missing transverse energy calculated from the vector sum of reconstructed jet with p_T>20 GeV, |η|<4.5, leptons and the calorimeter clusters not belonging to reconstructed objects.
- $\Delta\varphi_{min}$: minimum $\Delta\varphi$ between any of 3 leading jets and E_T^{miss}
- m_{eff} : scalar sum of the E_T^{miss} and up to
  - 3 leading jet p_T (0-lepton)
  - 4 leading jet p_T and identified lepton p_T (1-lepton)
- m_T : missing transverse mass calculated from the lepton and missing transverse energy by the following equation,

$$m_T = \sqrt{2(p_T^{lepton} E_T^{miss} - \vec{p}_T^{lepton} \cdot \vec{E}_T^{miss})}$$

Event Selection (0-lepton)

- lepton veto with p_T > 20 GeV (electron), 10 GeV (muon)
- jet p_T>130,50,50 GeV
- E_T^{miss} > 130 GeV

leading jet p_T and E_T^{miss} requirements are for trigger.

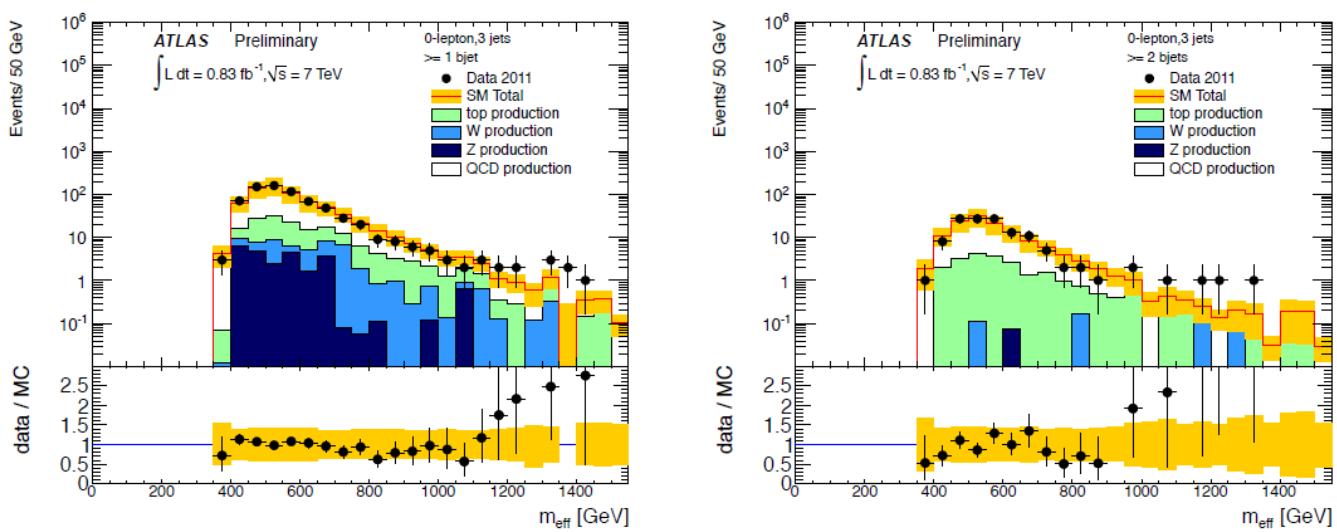
- $\Delta\varphi_{min}$ > 0.4 rad
- E_T^{miss}/m_{eff} > 0.25

To reduce QCD multi-jet background

- Prepare 4 signal regions
  - 3JA ($\geq$1 *b*-jet, m_{eff} > 500 GeV)
  - 3JB ($\geq$1 *b*-jet, m_{eff} > 700 GeV)
  - 3JC ($\geq$2 *b*-jet, m_{eff} > 500 GeV)
  - 3JD ($\geq$2 *b*-jet, m_{eff} > 700 GeV)
  - 1 signal region is chosen to show the best sensitivity for each signal point.

Background Estimation (I)

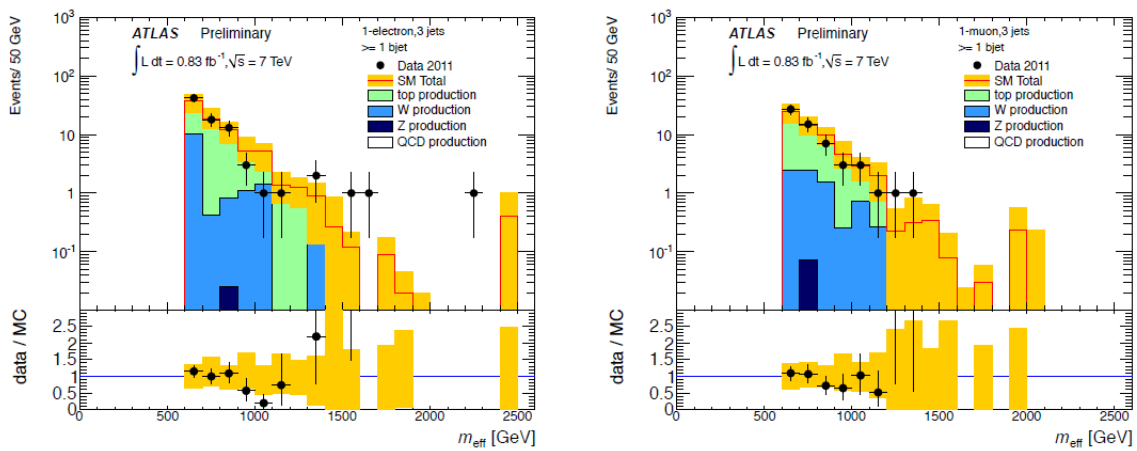
- QCD multi-jet data-driven (d-d) estimation
  - Smearing method : smear the momentum of jets in clean data events with low E_T^{miss} to generate "pseudoevents".
  - Normalization is taken from QCD dominant control region ($\Delta\varphi_{min} < 0.4$ rad)



m_{eff} distributions for QCD control region in 1 *b*-jet (left) and 2 *b*-jet channel.

Background Estimation (II)

- Non-QCD background (top, W/Z+jets)
  - MC-driven estimation
    - ttbar, single top : MC@NLO+HERWIG
    - W, Z+jets : ALPGEN+HERWIG
  - For validation of MC, similar kinematics region in 1-lepton channel is checked.
    - lepton p_T > 20 GeV
    - jet p_T>130,50,50GeV
    - 40 GeV < m_T < 100 GeV
    - m_{eff} > 600 GeV
    - 1 *b*-jet or 2 *b*-jet



m_{eff} distributions in 1-lepton control region. Electron (left) and muon (right) channel with 1 *b*-jet

1 *b*-jet case

	Top	W	Z	QCD	Total	Data(0.83fb^{-1})
electron	7.3	0.46	0.05	negligible	7.8 ± 2.4	7
muon	11.2	0.57	0	negligible	11.9 ± 3.1	12

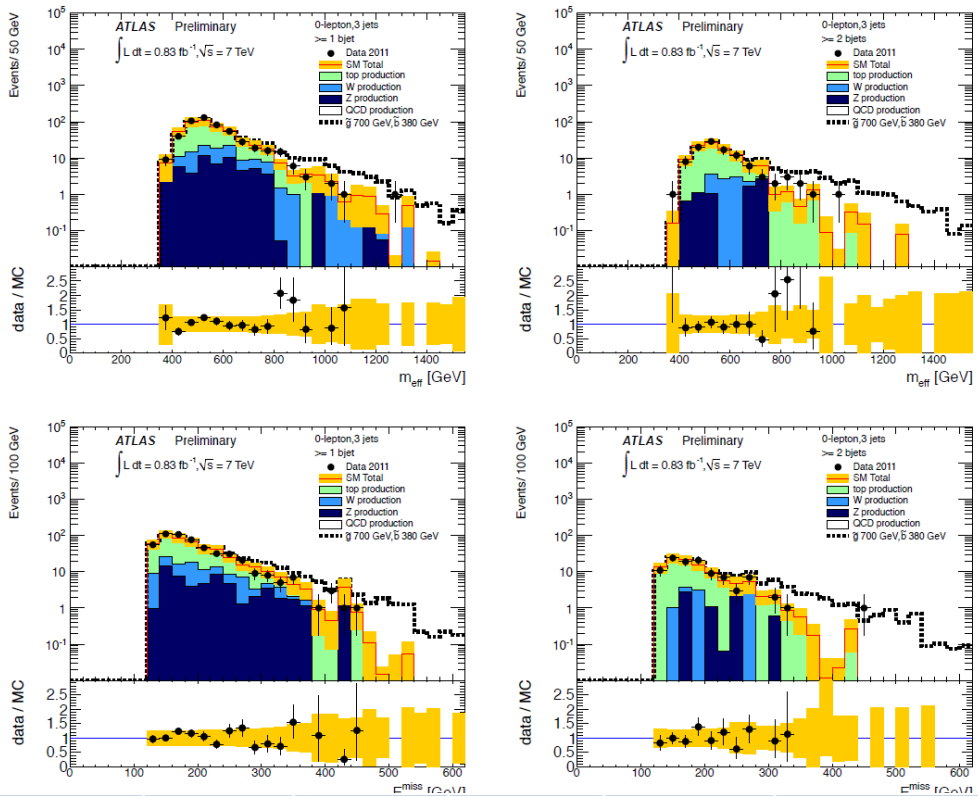
Systematic Uncertainties

- Pileup, jet energy scale and resolution
- *b*-tagging efficiency / light-jet fake rate
- Luminosity (3.7%)
- Theoretical uncertainties
  - ttbar: cross section, ISR/FSR variation (using AcerMC), generator dependence (MC@NLO, POWHEG, ALPGEN), Parton shower and fragmentation model (HERWIG, PYTHIA)
  - single top: cross section
  - W/Z+jets : N jets uncertainty sqrt(N)*24%, heavy flavor rescale
  - SUSY signals : Renormalization/factorizaton scale, PDF (CTEQ6.6M PDFs)

systematic uncertainties for ttbar

	MC stat.	Jet	*b*-tag	Lumi	xsec	total w/o theory	theory
3JA($\geq$1 *b*-jet, m_{eff}>500 GeV)	±4 %	± 23 %	± 10 %	± 3.7 %	± 8 %	±27%	+28 % -17 %
3JB($\geq$1 *b*-jet, m_{eff}>700 GeV)	± 9 %	± 25 %	± 8 %	± 3.7 %	± 8 %	±29%	+33% -18 %
3JC($\geq$2 *b*-jet, m_{eff}>500 GeV)	± 6 %	± 25 %	± 26 %	± 3.7 %	± 8 %	±38%	+28% -17 %
3JD($\geq$2 *b*-jet, m_{eff}>700 GeV)	± 16 %	± 19 %	± 26 %	± 3.7 %	± 8 %	±37%	+33% -18 %

Results (0-lepton)

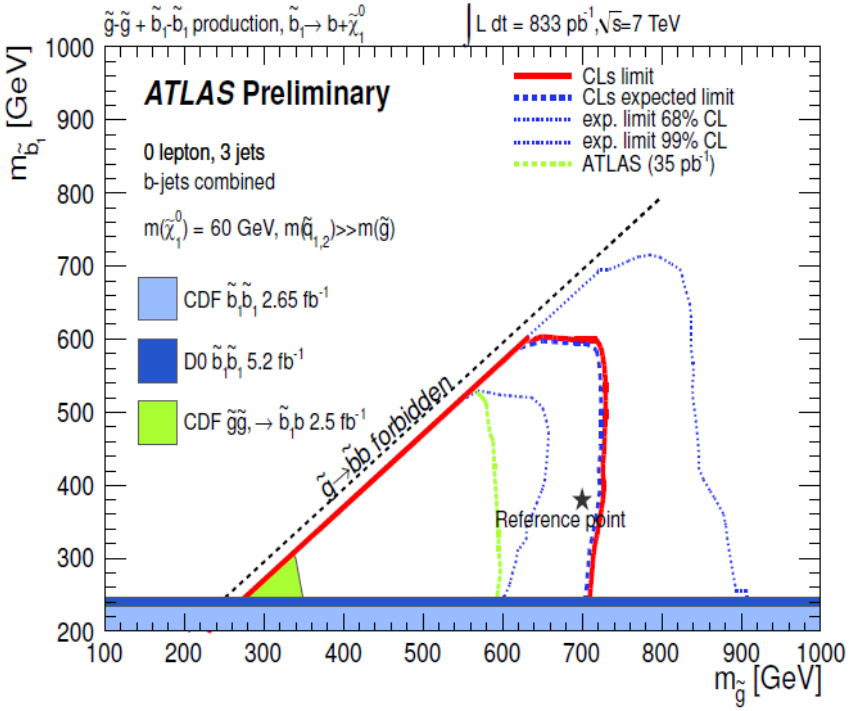


- m_{eff} (top) and E_T^{miss} (bottom) distributions for 1 *b*-jet (left) and 2 *b*-jet (right)
- $\tilde{g} \rightarrow b\tilde{b}_1$ signal is shown with stacked dotted line.

limits on non-SM contributions

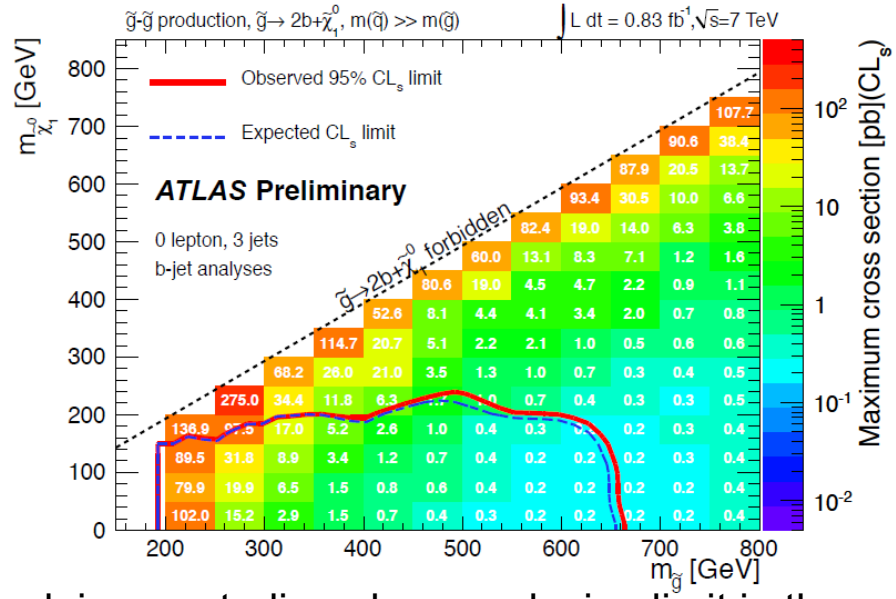
Signal Region	Top	W/Z	QCD	Total	Data(0.83fb^{-1})	95% CL Nevents	95% CL σ(pb)
3JA(1 *b*-jet, m_{eff}>500GeV)	221^{+82}_{-68}	121±61	15±7	356^{+103}_{-92}	361	240	0.288
3JB(1 *b*-jet, m_{eff}>700GeV)	37^{+15}_{-12}	31±19	1.9±0.9	70^{+24}_{-22}	63	51	0.061
3JC(2 *b*-jet, m_{eff}>500GeV)	55^{+25}_{-22}	20±12	3.6±1.8	79^{+28}_{-25}	76	65	0.078
3JD(2 *b*-jet, m_{eff}>700GeV)	$7.8^{+3.5}_{-2.9}$	5±4	0.5±0.3	$13.0^{+5.6}_{-5.2}$	12	14	0.017

Interpretation (0-lepton)



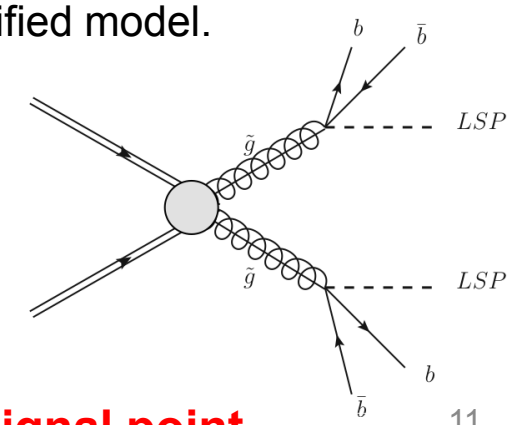
gluino-sbottom plane exclusion limit with m(~*g*)>m(~b_1). The lightest neutralino mass is set to 60 GeV.

gluino mass below 720 GeV (and sbottom mass up to 600 GeV) is excluded with 95% CL.



gluino-neutralino plane exclusion limit in the ~*g*→*bb*+LSP simplified model.

gluoino mass below 660 GeV (and LSP up to 200GeV) is excluded with 95% CL.

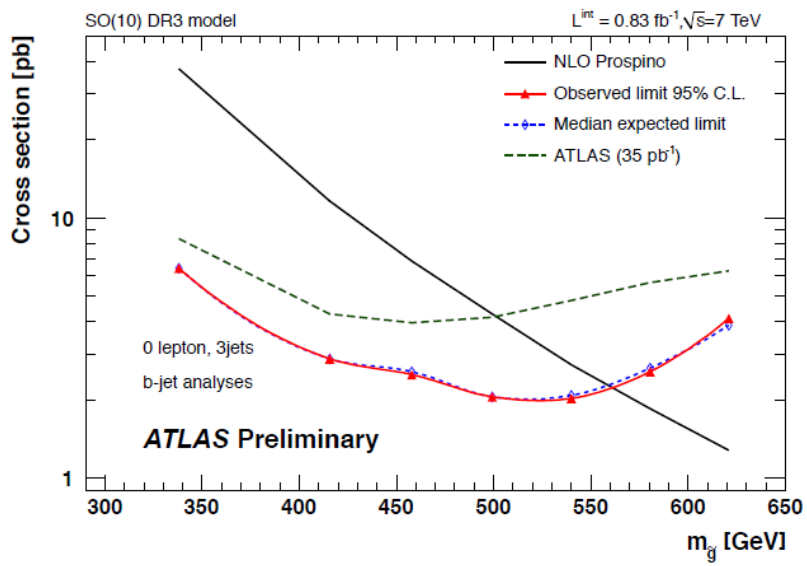


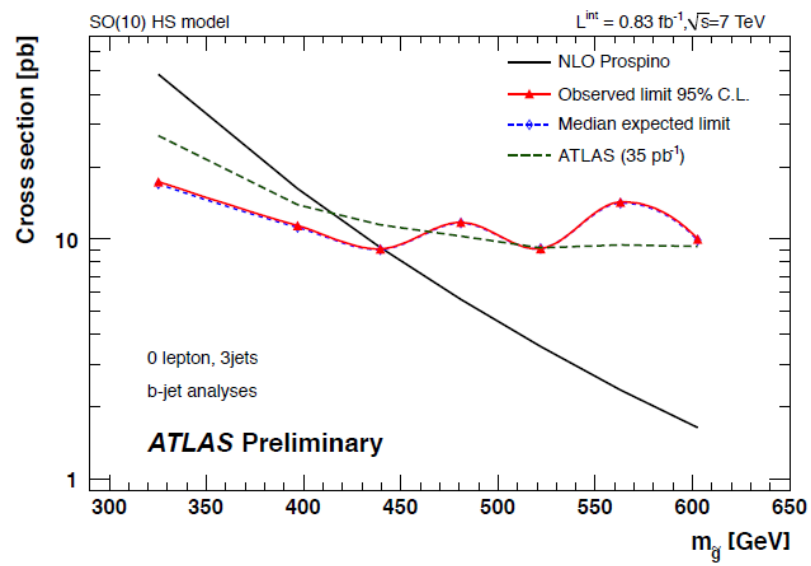
The best selection is chosen from 3J A-D for each signal point

Interpretation (0-lepton)

Interpretation in the *b*-jet enrich specific models:

- Grand Unification Theories based on the gauge group SO(10),
  D-term splitting model, DR3 and Higgs splitting model, HS (H. Baer, S. Kraml, A. Lessa, S. Sekmen, JHEP 1002 (2010) 055)
- In these models, squarks (~10 TeV) are much heavier than gluino. But third generation squarks (~1 TeV) are lighter than them, so gluino 3-body decay to *bb* is enhanced.





95% CL limit on the production cross section for DR3 (left) and HS models (right) as a function of gluino mass.

Gluinos with masses below 570 GeV and 450 GeV are excluded for the DR3 and HS models.

Event Selection (1-lepton)

- exactly one lepton (electron or muon)
  - electron : *tight* ID, p_T > 25 GeV (requirement from electron trigger), track isolation
  - muon : p_T > 20 GeV (requirement from muon trigger), track isolation
- 4 jet with p_T > 50 GeV
- E_T^{miss} > 80 GeV
- m_T > 100 GeV
- at least 1 *b*-jet
- m_{eff} > 600 GeV

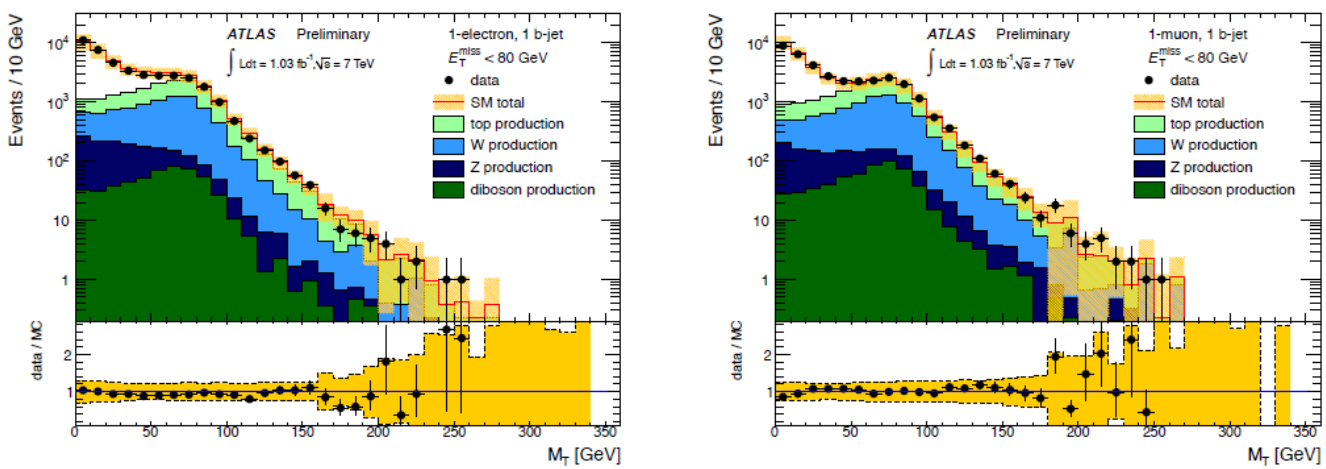
Background Estimation

- QCD multi-jet data-driven (d-d) estimation
  - matrix method : decompose *loose* and *tight* selected leptons into real (EW) and fake (QCD).

$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}}$$

$$N^{\text{tight}} = \varepsilon_{\text{real}} N^{\text{loose}}_{\text{real}} + \varepsilon_{\text{fake}} N^{\text{tight}}_{\text{fake}}$$

$$N^{\text{tight}}_{\text{fake}} = \frac{\varepsilon_{\text{real}}}{\varepsilon_{\text{real}} - \varepsilon_{\text{fake}}} (\varepsilon_{\text{real}} N^{\text{loose}} + N^{\text{tight}})$$

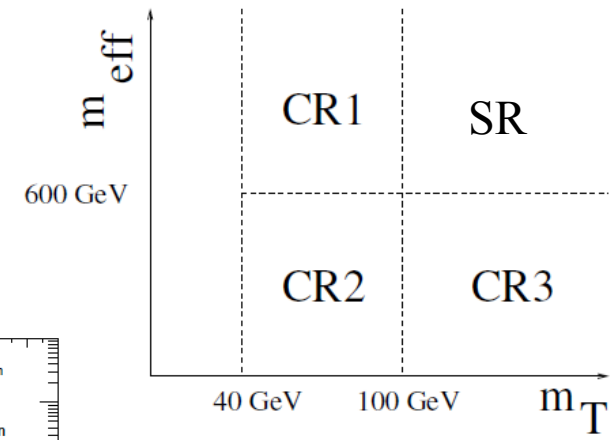


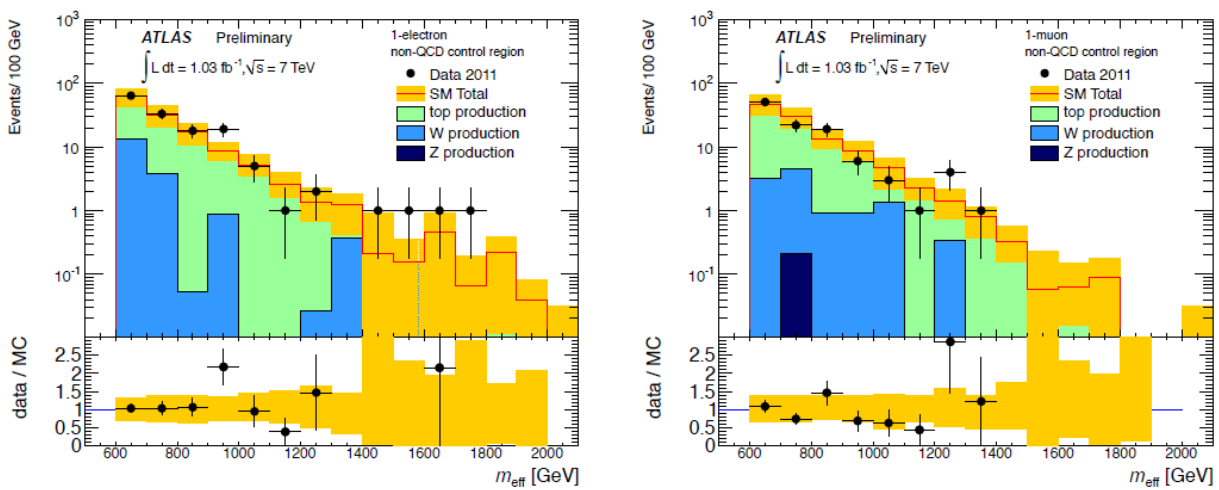
m_T distributions for QCD control region in electron (left) and muon (right) channel

Background Estimation

- ttbar, single top, W/Z+jets semi-data-driven estimation
  - Obtain scale factor in control region (CR) defined by 40 GeV < m_T < 100 GeV and m_{eff} > 600 GeV.
  - Then propagate it to signal region (SR).

$$N_{\text{data}}^{\text{SR}} = N_{\text{data}}^{\text{CR}} \frac{N_{\text{MC}}^{\text{SR}}}{N_{\text{MC}}^{\text{CR}}} = N_{\text{data}}^{\text{CR}} T_{\text{MC}}$$

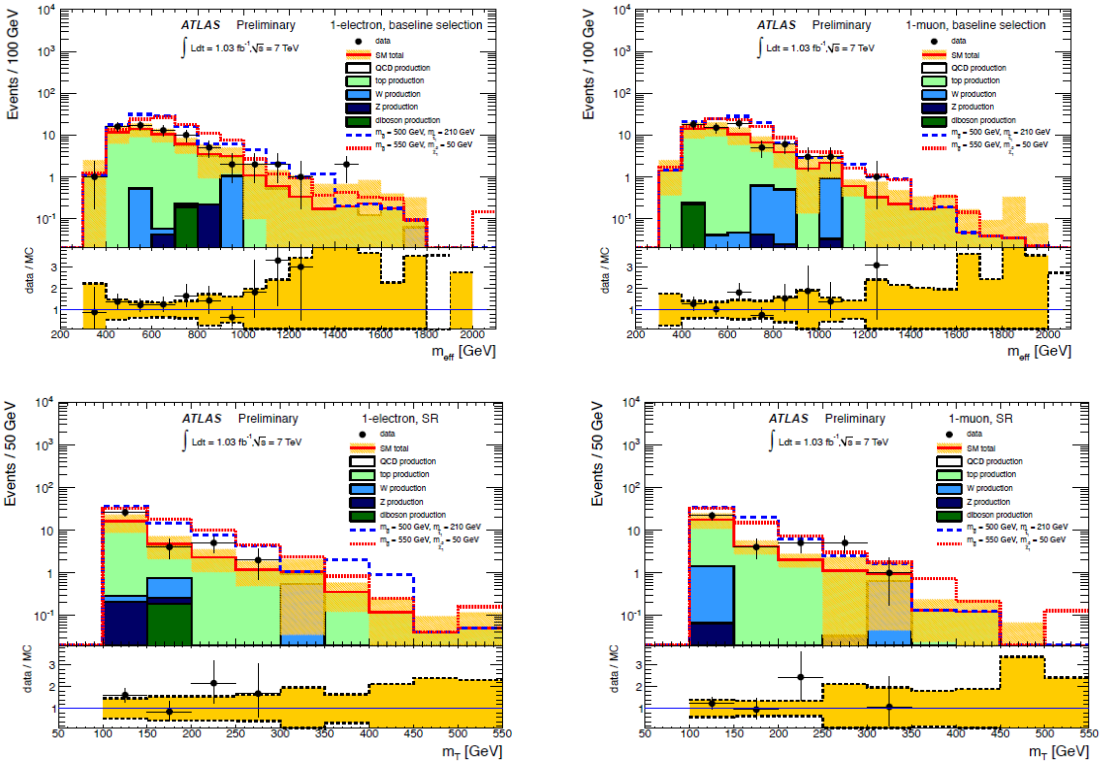




m_{eff} distributions for control region in electron (left) and muon (right) channel

Other control regions are also checked for validation and reasonable agreement is obtained.

Results (1-lepton)



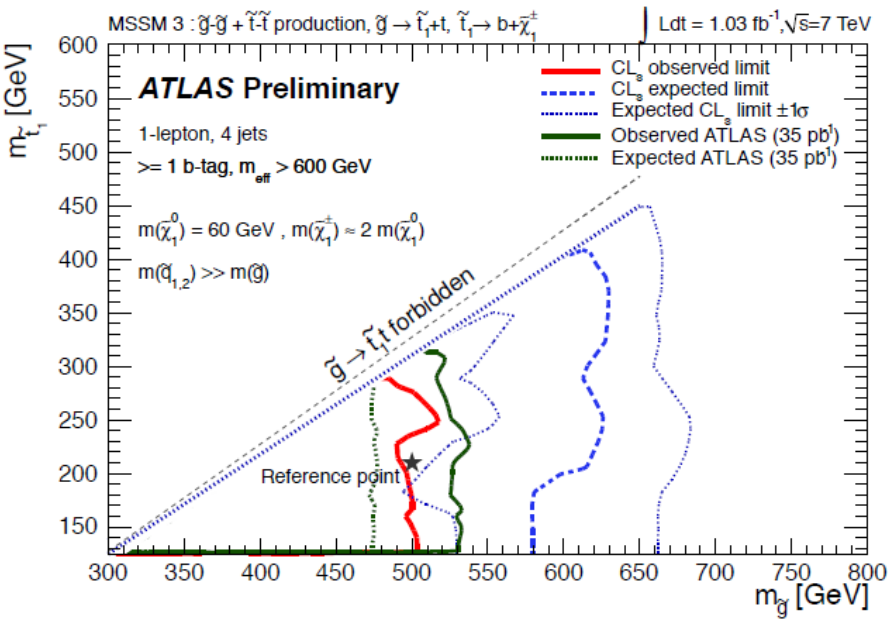
- m_{eff} (top) and m_T (bottom) distributions for electron (left) and muon (right) channels
- $\tilde{g} \rightarrow t\tilde{t}_1$ signal are shown.
- model independent 95% CL upper limit on the effective cross-section

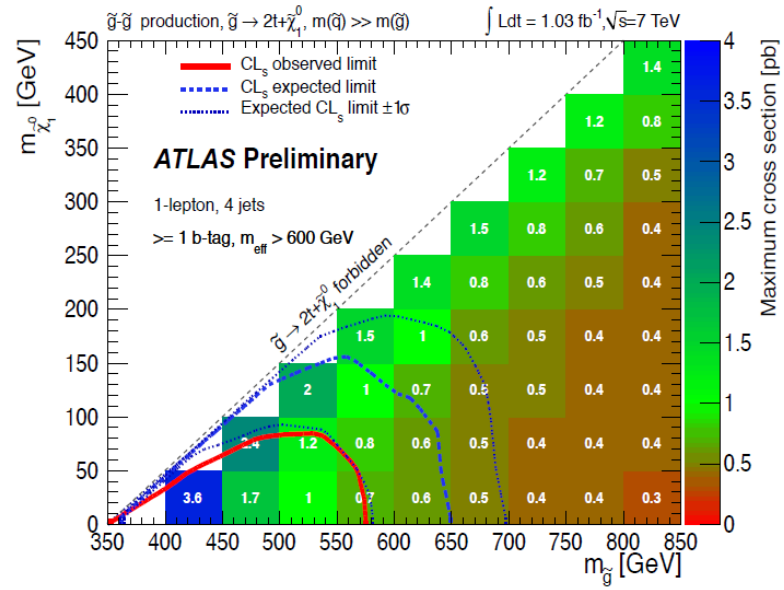
  31 fb (expected)

  46 fb (observed)

	Top	W/Z	QCD(d-d)	Total(MC)	Total(d-d)	Data(1.03fb^{-1})
electron	24±14	0.6±0.9	0.9±1.0	26 ± 14	25.5±5.3	37
muon	24±13	1.4±1.4	< 0.6	25 ± 14	27.3±8.7	37

Interpretation (1-lepton)



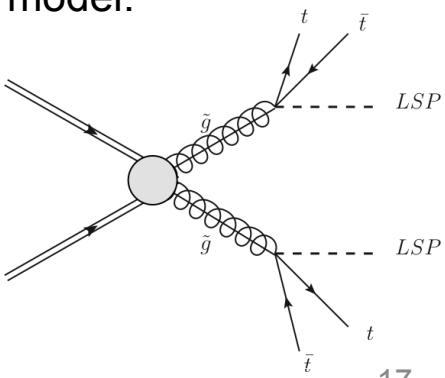


gluino-stop plane exclusion limit with m(~*g*)>m(~t_1). The lightest neutralino mass is set to 60 GeV and 2nd lightest neutralino and lightest chargino masses are 120GeV.

gluino mass below 500 GeV is excluded with 95% CL.

gluino-neutralino plane exclusion limit in ~*g*→*tt*+LSP simplified model.

gluiono mass below 570 GeV (and up to LSP mass 40 GeV) is excluded with 95% CL.

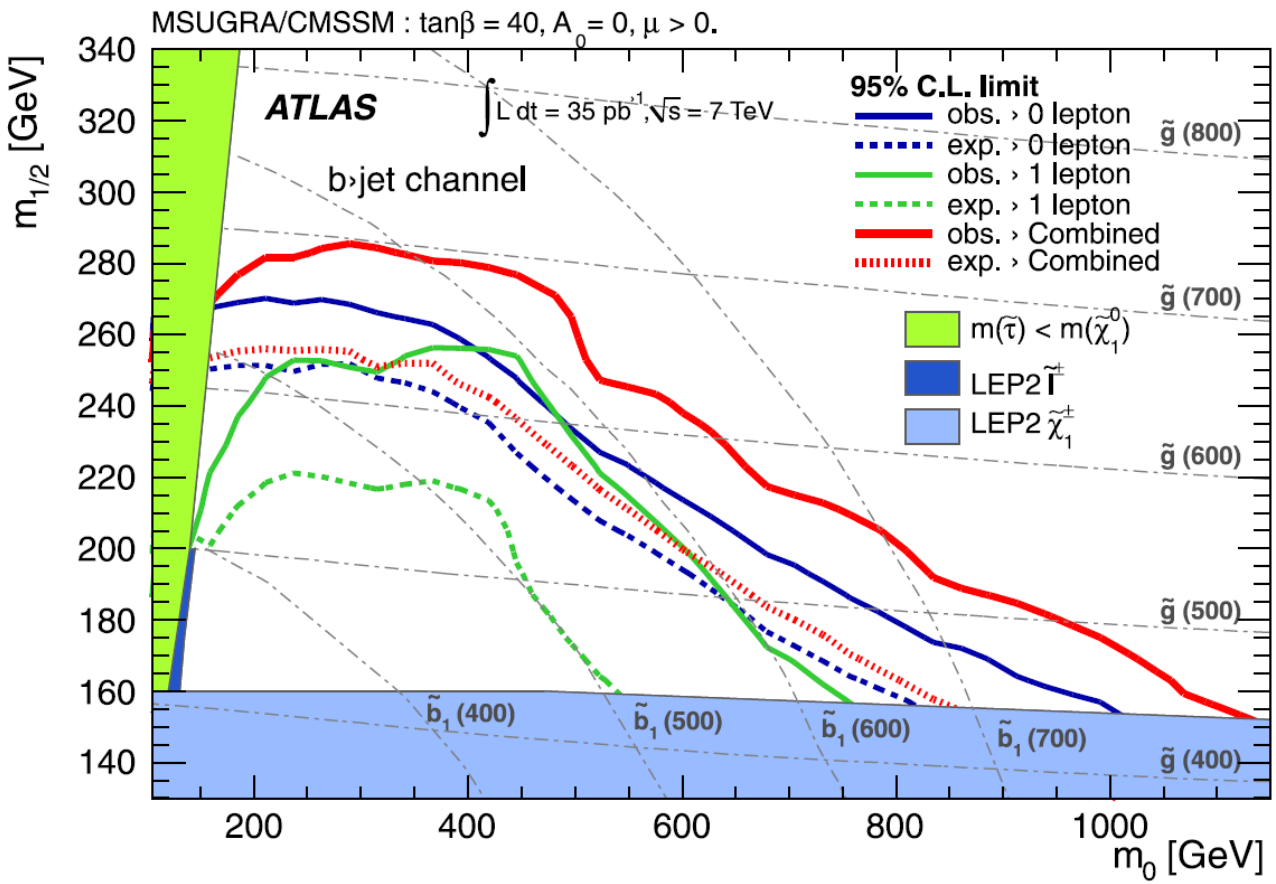


Conclusion

- Updates on the search for supersymmetry in final states with missing transverse momentum, *b*-jet and 0/1-lepton are presented.
  - In the *pp* collision of 7 TeV at LHC with the ATLAS detector, integrated luminosity of 0.83 fb^{-1}/1.03 fb^{-1}
- The results are used to set limits on the models of gluino→sbottom or gluino→stop cascade decay.
  - In sbottom case, gluino masses below 720 GeV are excluded at 95% CL.
  - In stop case, gluino masses below 570 GeV for LSP masses below 40GeV are excluded at 95% CL.
- **Note : mSUGRA/CMSSM interpretation will be done with the full 2011 dataset.**

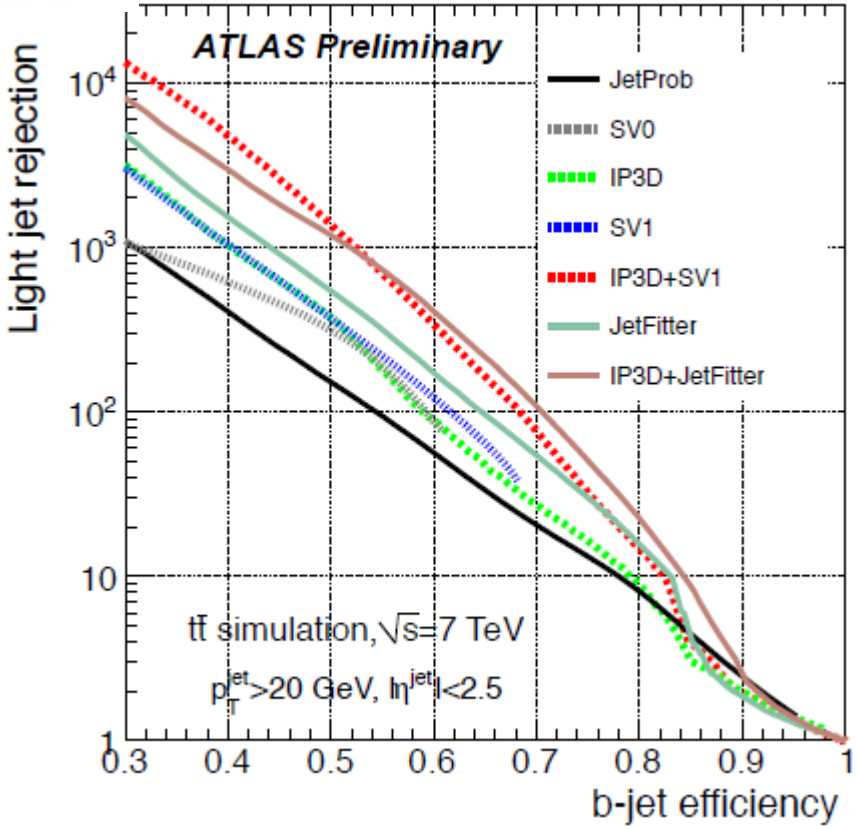
Backup

mSUGRA Limit at 35pb^{-1}



ATLAS Collaboration, Physics Letters B Volume 701, Issue 4, July 2011, p.398-416

b-tagging Performance

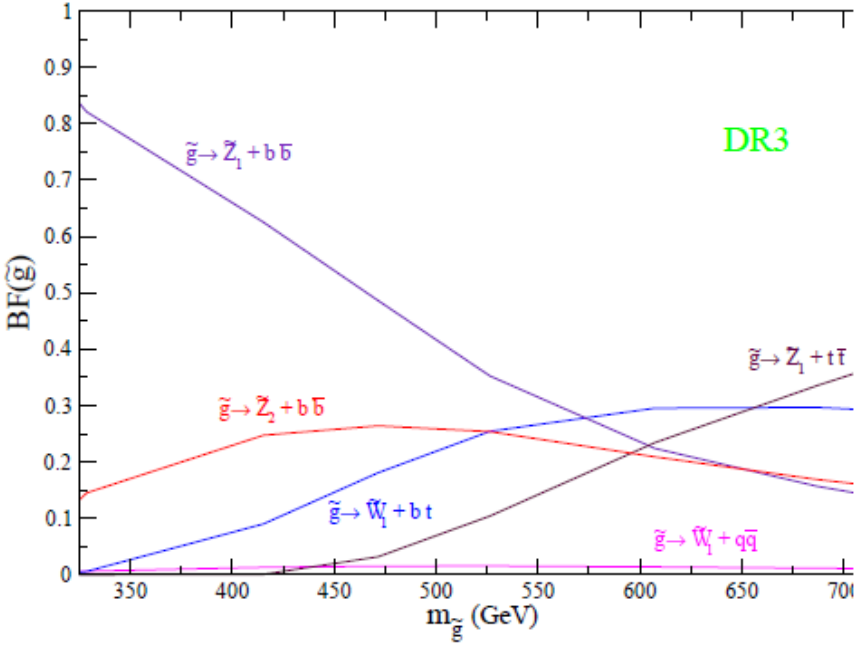


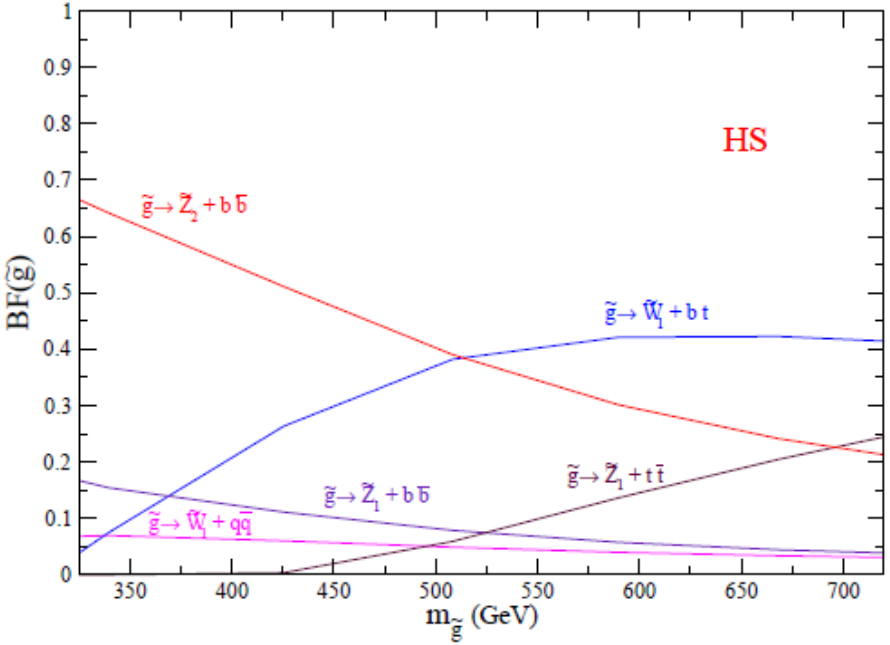
- IP3D+JetFitter means secondary vertex- / impact parameter-based tagger combined
- SV0 means secondary vertex-based tagger

b-tagging algorithm performances based on simulated ttbar events

ATLAS Collaboration, ATLAS-CONF-2011-102 (2011).

SO(10) Models





BR for gluino decays in DR3 (left) and HS models (right).