Inclusive searches for squarks and gluinos with the ATLAS detector

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on behalf of the ATLAS collaboration

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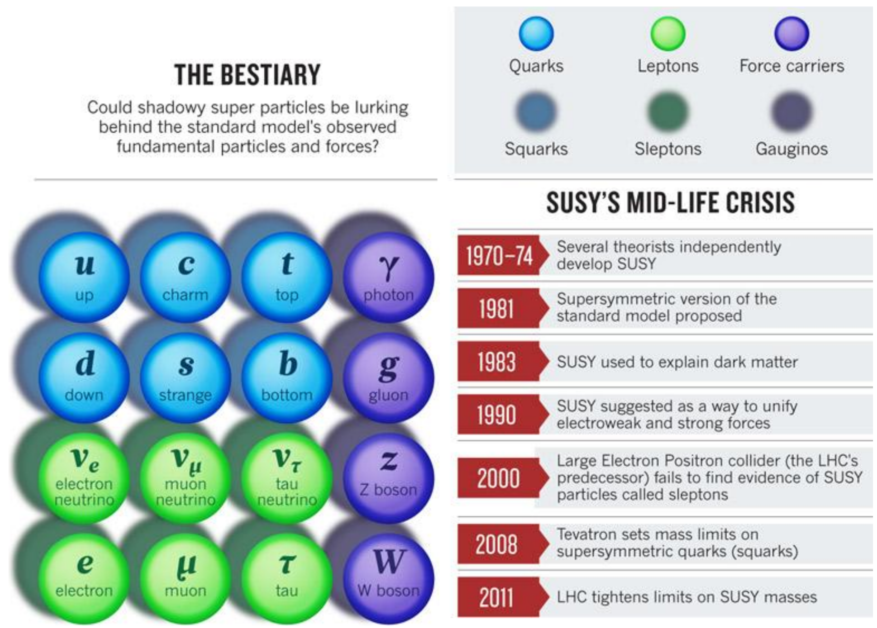
Outline

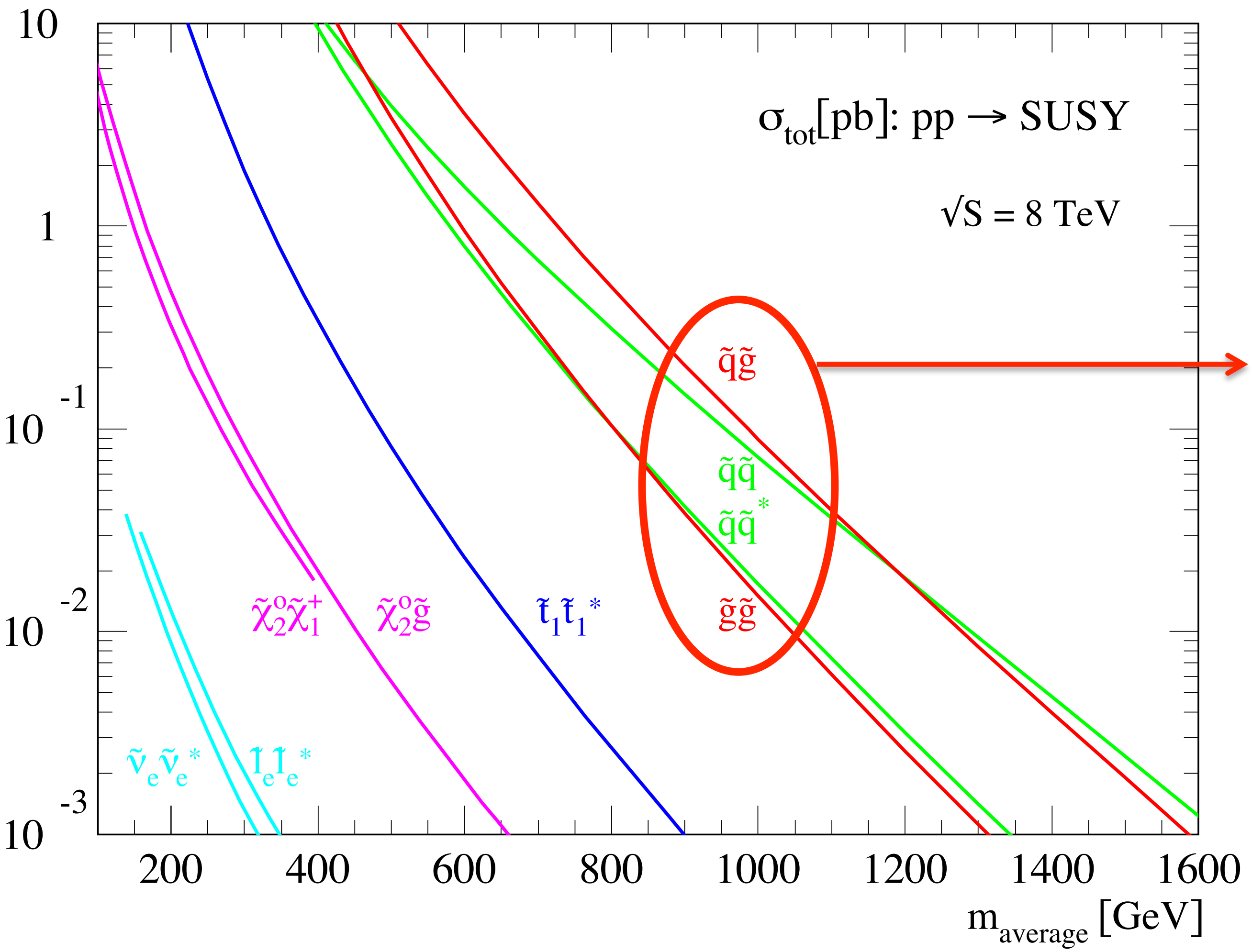
- **Introduction**
  - **Strong Production Supersymmetry**
  - **ATLAS SUSY search strategy**
- **1-2 taus + jets+ EtMiss**
- **2 same-sign leptons + 0-3 b-jets + EtMiss**
- **Z(ll) + jets +EtMiss**
- **Summary**

SOURCE: FERMILAB



Introduction

Strong Production Supersymmetry



Strong production channels:

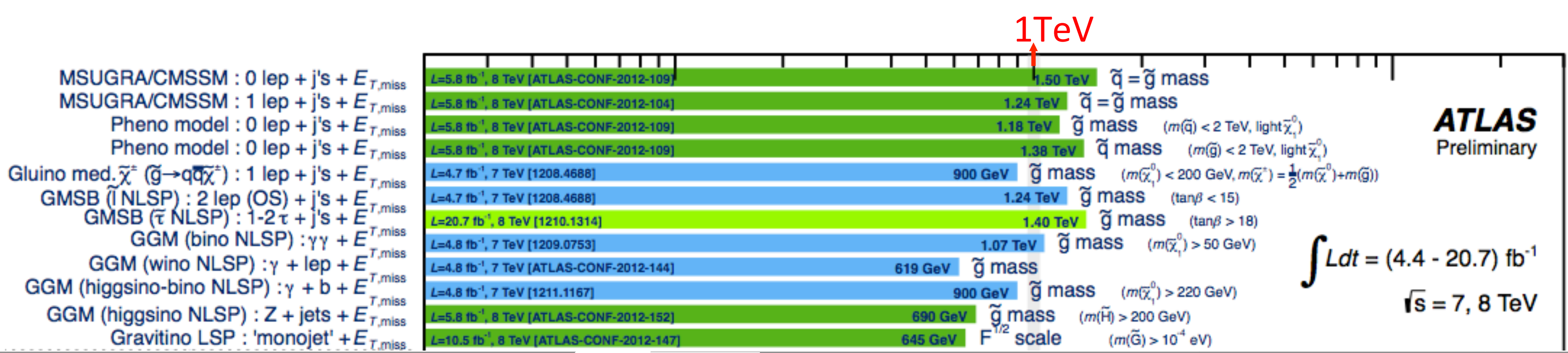
- copious production at hadron colliders
- EtMiss based generic search channels

ATLAS SUSY Search Strategy

- **Due to the high number of signatures to be searched, strategy based on the search for different final states to be interpreted in various SUSY models and scenarios.**
  - Inclusive SUSY searches:
    - ✓ 2 SS leptons + (0-3) b-jets + EtMiss
    - ✓ 1-2 taus + jets + EtMiss
    - ✓ Z + jets + EtMiss
    - ✓ 0 leptons + jets + EtMiss
    - ✓ 1 lepton + jets +EtMiss
    - ✓ (0-2) leptons + (0-1) b-jets multichannel (razor)
    - ✓ 1 photon + ≥ bjet + EtMiss
    - ✓ …

Latest results with 8TeV. **This talk** (applies to the first three items)

ATLAS SUSY public results web page:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults



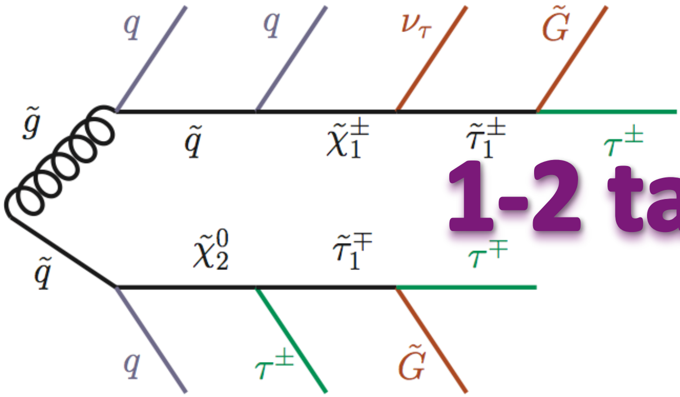
ATLAS SUSY Search Strategy

SUSY events in our data?

- **Define Signal Region(s) (SR):** set of cuts (on EtMiss, jet multiplicity, etc) that favour signal over background

- **Background events in our SR?**
  - Minor: MC-only estimation
  - Major: semi data-driven
    - ✓ Define **Control Regions (CR):** negligible signal
    - ✓ Normalise MC to match data in CR (obtain transfer factor)
    - ✓ Apply transfer factor to MC estimation of SR bkg
  - QCD multijets: data-driven

- **Discovery/Exclusion fit:**
  - CLs exclusion limits or discovery



1-2 taus + jets + EtMiss

$\sqrt{s}$ = 8 TeV

L = 20.7 fb^{-1} (full 2012 lumi)

ATLAS-CONF-2013-026

Final states with hadronically decaying τ's and **veto e/mu**:

- **1τ** with veto on additional τ leptons
- **≥ 2 τ** leptons

Interpretation and limits in the context of: GMSB, nGM, mSUGRA/cMSSM

The 3 models allow NLSP = stau ➡ τ's in final states

Event Selection

1-2 taus + jets + EtMiss

- 3 Signal Regions (SR) optimized to maximize the sensitivity to different SUSY models:

	1τ SR	2τ GMSB SR	2τ nGM SR
Pre-selection	$p_T^{\text{jet1}} > 130$ GeV, $p_T^{\text{jet2}} > 30$ GeV $E_T^{\text{miss}} > 150$ GeV		
Taus	$N_\tau^{\text{medium}} = 1$, $p_T^\tau > 30$ GeV	$N_\tau^{\text{loose}} \geq 2$, $p_T^\tau > 20$ GeV	
Light leptons	$N_\ell = 0$		
QCD rejection	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{\text{miss}}}) > 0.3$ rad $E_T^{\text{miss}}/m_{\text{eff}} > 0.3$	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{\text{miss}}}) > 0.3$ rad	
Signal cuts	$m_T^\tau > 140$ GeV $H_T > 800$ GeV	$m_T^{\tau_1} + m_T^{\tau_2} \geq 150$ GeV $H_T > 900$ GeV	$m_T^{\tau_1} + m_T^{\tau_2} \geq 250$ GeV $H_T > 600$ GeV $N_{\text{jet}} \geq 4$

For definitions of variables go to backup slide 26

Background Estimation

1-2 taus + jets + EtMiss

Dominant backgrounds:

1τ SR

Z + jets
W + jets
top

- Events divided in:
  - 1 true tau
  - 1 fake tau (a jet is mis-identified as a tau)

Composition of true and fake taus in CR and SR **may differ** => necessary to measure **separate scaling factors** for the two cases

2τ GMSB SR

Z + jets
W + jets
top

- W and top backgrounds:
  - 1 true tau
  - the others a fake
- Z+jets events dominated by $Z \rightarrow \tau\tau$ decays

True and fake tau canditates **composition** is **the same** in the CR and SR. **No need to separate CRs** in true or fake dominated

2τ nGM SR

top

- overall dominant background

⬇

only one CR is defined

√s = 8 TeV
L = 20.7 fb^{-1} (full 2012 lumi)

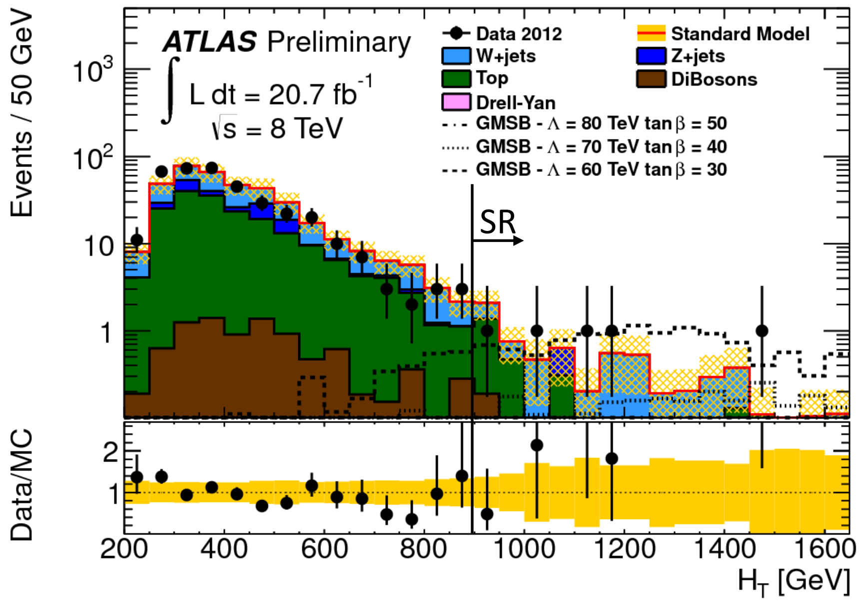
Results

1-2 taus + jets + EtMiss

	1τ SR	2τ GMSB SR	2τ nGM SR
Total background	4.9±1.5 ±1.3	7.2 ± 1.3 ± 1.6	3.5 ± 1.1 ± 1.9
Data	3	5	1

Expected bkg events
Observed data events

2τ GMSB SR



NO SIGNIFICANT EXCESS IN ANY OF THE SIGNAL REGIONS

Upper limits

Obs (exp) limit on signal events	8.2 $(8.3^{+3.1}_{-2.2})$	8.4 $(9.9^{+4.8}_{-3.3})$	5.4 $(7.6^{+3.1}_{-2.2})$
Obs limit on Cross Section (fb)	0.40	0.41	0.26

signal events
cross sections

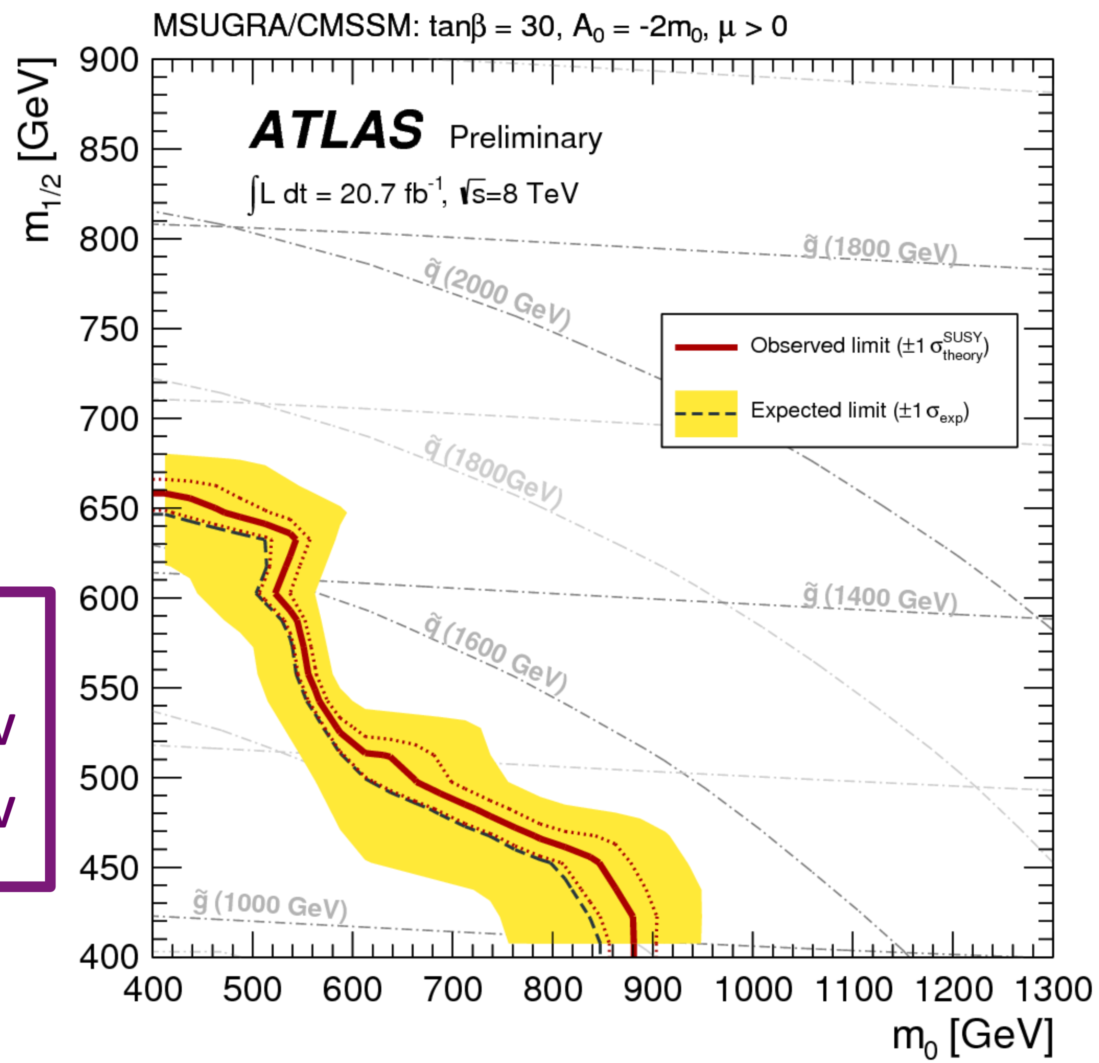
Results

mSUGRA/cMSSM
1τ analysis

1-2 taus + jets + EtMiss

mSUGRA/cMSSM

- lightest Higgs boson is compatible with the recent discovery of a Higgs-boson
- LSP = lightest neutralino



Exclusion limits:

low m1/2 -> values of m0 up to 860 GeV

low m0 -> values of m1/2 up to 650 GeV

Results

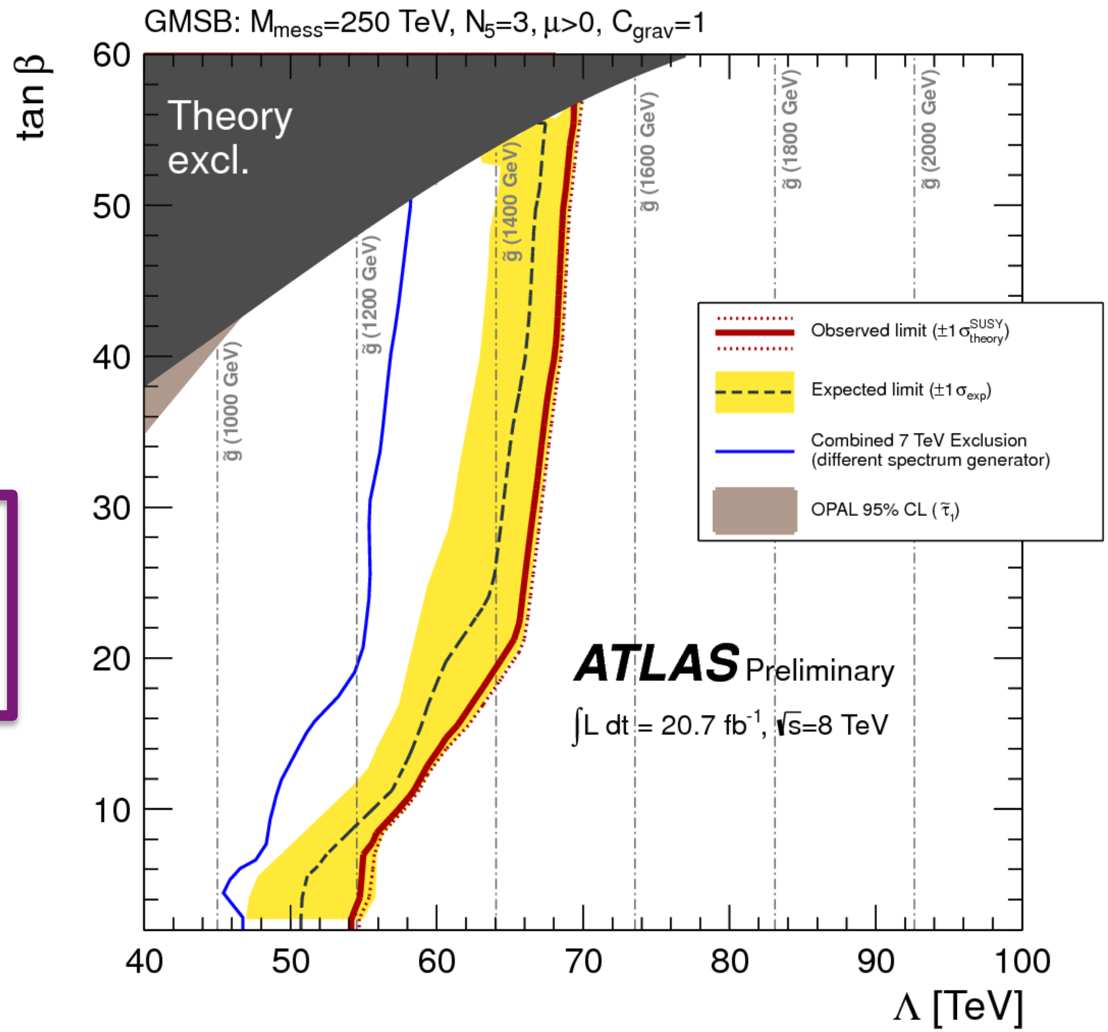
GMSB
combination of 1τ and 2τ analysis

1-2 taus + jets + EtMiss

Minimal GMSB

(Gauge-Mediated Supersymmetry Breaking)

- LSP = very light gravitino
- **NLSP = stau**



Exclusion limits:

- on **Λ = 54 TeV** independent of tanß
- **Λ = 70 TeV** for tanß > 50

$\sqrt{s}$ = 8 TeV
L = 20.7 fb^{-1} (full 2012 lumi)

Results

nGM
2τ analysis with Njet ≥ 4

1-2 taus + jets + EtMiss

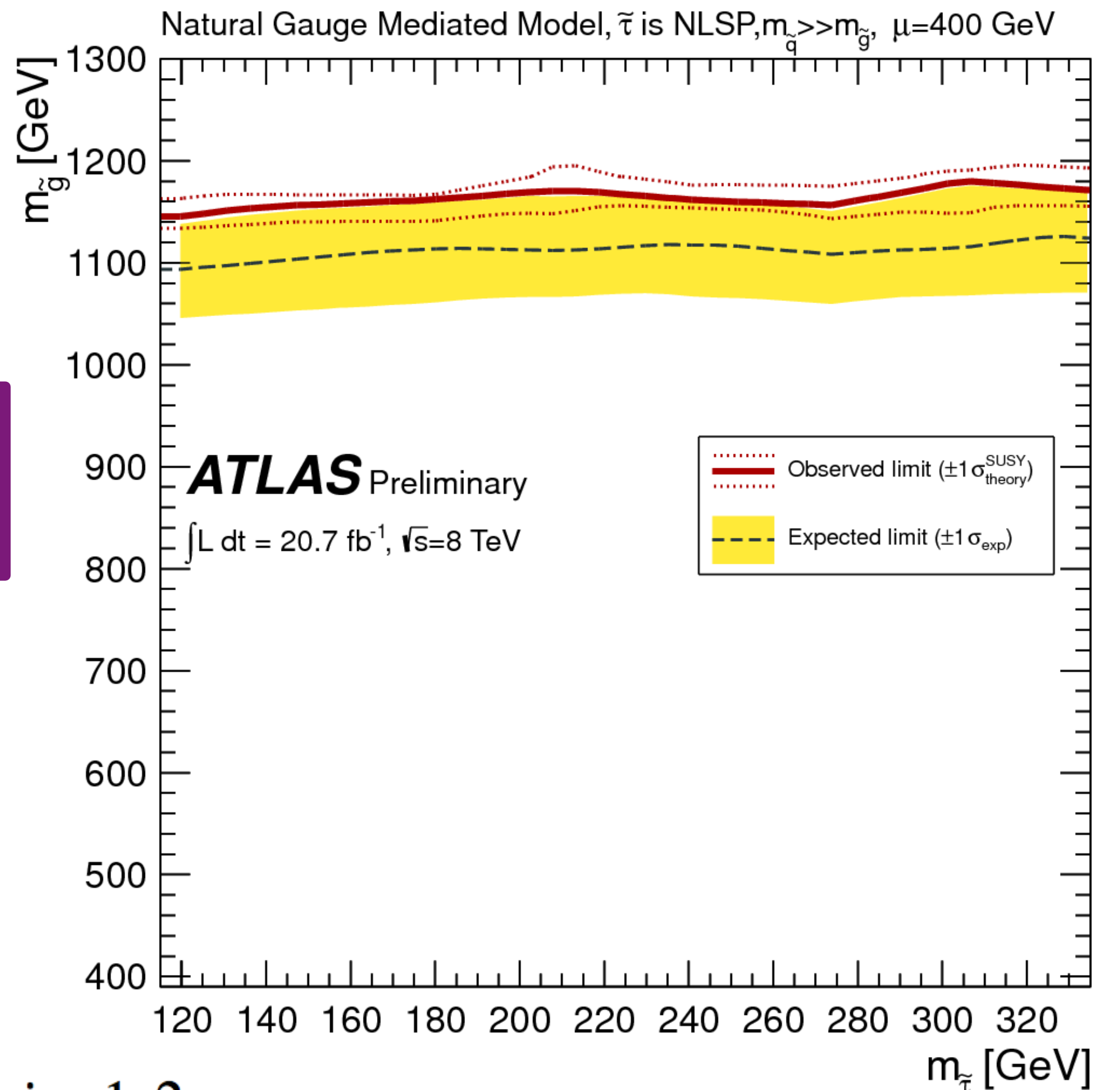
nGM

(natural Gauge Mediation)

- **NLSP = stau**

Exclusion limit:

- on the **mass(gluino)** is **1140 GeV**



$$\tilde{g} \to q\bar{q}\tilde{\chi}_i^0 \to q\bar{q}\tau\,\tilde{\tau} \to q\bar{q}\tau\tau\tilde{G}, \text{ with } i = 1, 2$$

2 same-sign leptons + 0-3 b-jets + EtMiss

$\tilde{g} \to q\tilde{q}$, $\tilde{q} \to q'\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to W^{\pm(*)}\tilde{\chi}_1^0$ — Gluino-squark (via W)

$\tilde{\chi}_1^{\pm} \to \tilde{\ell}\nu, \ell\tilde{\nu}$; $\tilde{q} \to q\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to \tilde{\ell}\ell, \tilde{\nu}\nu$ — Gluino-squark (via slepton)

$\tilde{q} \to q'\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm} \to \tilde{\ell}\nu, \ell\tilde{\nu}$; $\tilde{q} \to q\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to \tilde{\ell}\ell, \tilde{\nu}\nu$ — direct squark (via slepton)

√s = 8 TeV

L = 20.7 fb^{-1} (full 2012 lumi)

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Same-sign lepton pairs (ee, eμ, μμ) + :

- 0 b-jets (b-jet veto)
- ≥ 1 b-jets
- ≥ 3 b-jets

Interpretation and limits in the context:

- mSUGRA/CMSSM
- Simplified models:
  - Gluino-squark (via W or via sleptons)
  - Direct-squark (via sleptons)
  - Others

(Gluino-squark and Direct-squark: 1st and 2nd squark generations only)

Detailed info: Carolina Deluca's talk
at 17:50 today

√s = 8 TeV
L = 20.7 fb^{-1} (full 2012 lumi)

Results

2 SS lept + 0-3 b-jets

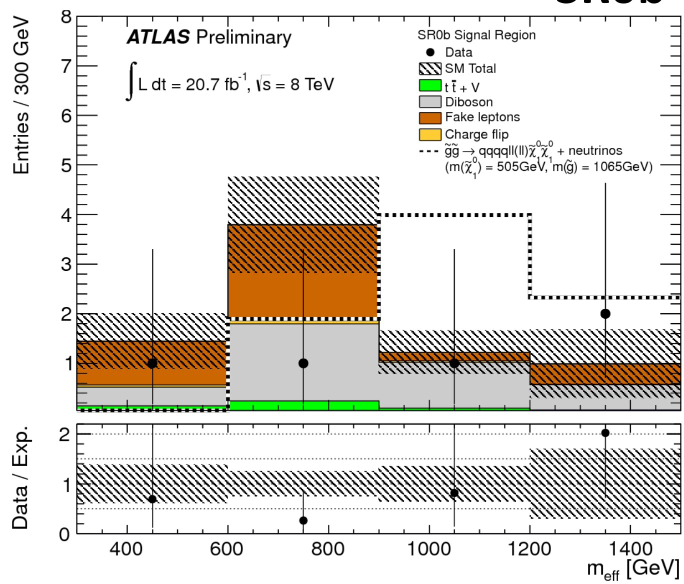
	SR0b	SR1b	SR3b
Observed events	5	11	1
Expected background events	7.5 ± 3.2	10.1 ± 3.9	1.8 ± 1.3

Observed data events

Expected bkg events

NO SIGNIFICANT EXCESS IN ANY OF THE SIGNAL REGIONS

SR0b



Upper limits on
visible cross sections and
observed and expected **number of signal events**
from models of physics beyond the SM

Signal regions	$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{exp}
SR0b	0.33	6.7	$7.9^{+2.6}_{-2.0}$
SR1b	0.53	11.0	$6.8^{+2.6}_{-1.5}$
SR3b	0.34	7.0	$5.9^{+2.4}_{-1.3}$

√s = 8 TeV
L = 20.7 fb^{-1} (full 2012 lumi)

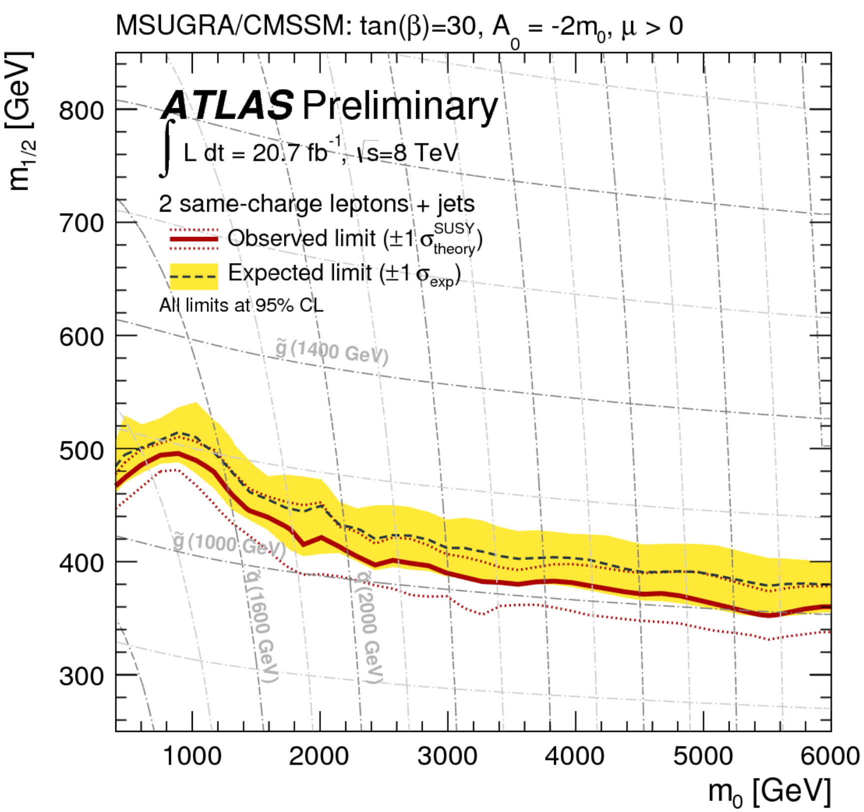
Results

lightest neutralino = LSP

Combination of the 3 SRs

2 SS lept + 0-3 b-jets

mSUGRA/CMSSM:
- exclusion limits complementary to tau analysis (slide 10)

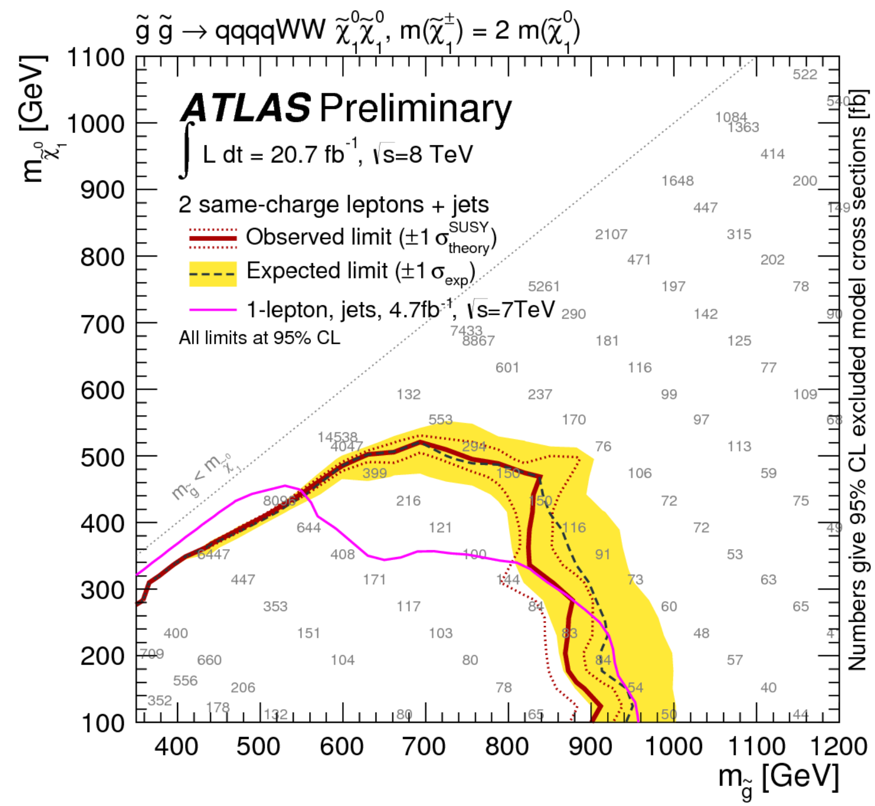


Gluino-squark (via W):
- gluino-gluino production

$\tilde{g} \rightarrow q\,\tilde{q}$, $\tilde{q} \rightarrow q'\,\tilde{\chi}_1^{\pm} \rightarrow W^{\pm(*)}\tilde{\chi}_1^0$

Exlusion limit:

on m($\tilde{g}$) = 750-830 GeV for m($\tilde{\chi}_1^0$) up to 450 GeV



√s = 8 TeV
L = 20.7 fb^{-1} (full 2012 lumi)

Results

lightest neutralino = LSP

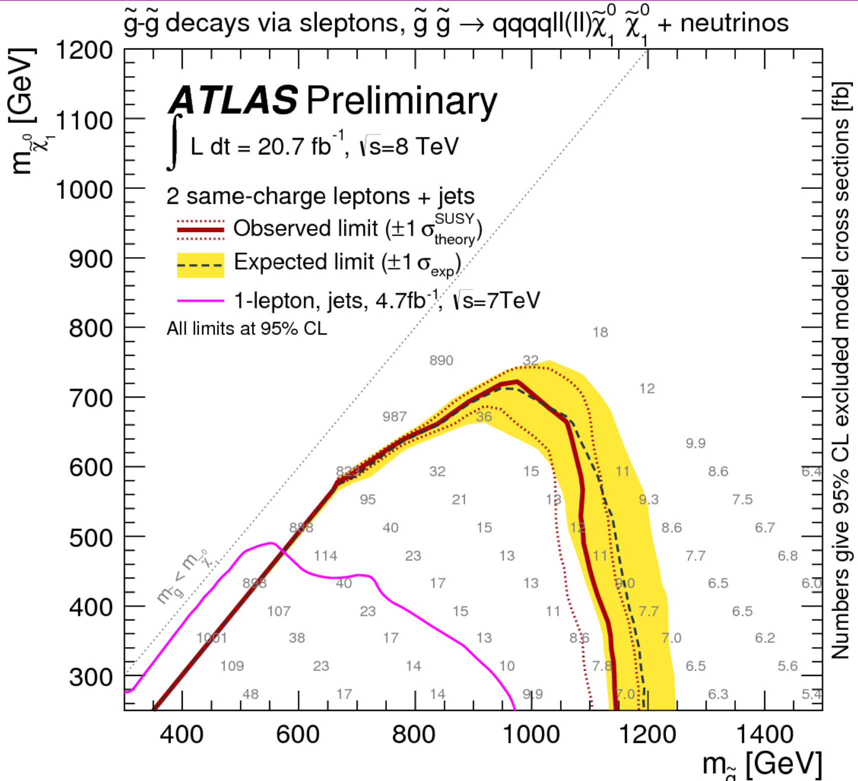
Combination of the 3 SRs

2 SS lept + 0-3 b-jets

Gluino-squark (via sleptons):
- gluino-gluino production

$$\tilde{g} \rightarrow q\,\tilde{q}$$
$$\hookrightarrow q'\,\tilde{\chi}_1^{\pm} \rightarrow \tilde{\ell}\nu, \ell\tilde{\nu}$$
$$\hookrightarrow q\,\tilde{\chi}_2^0 \rightarrow \tilde{\ell}\ell, \tilde{\nu}\nu$$

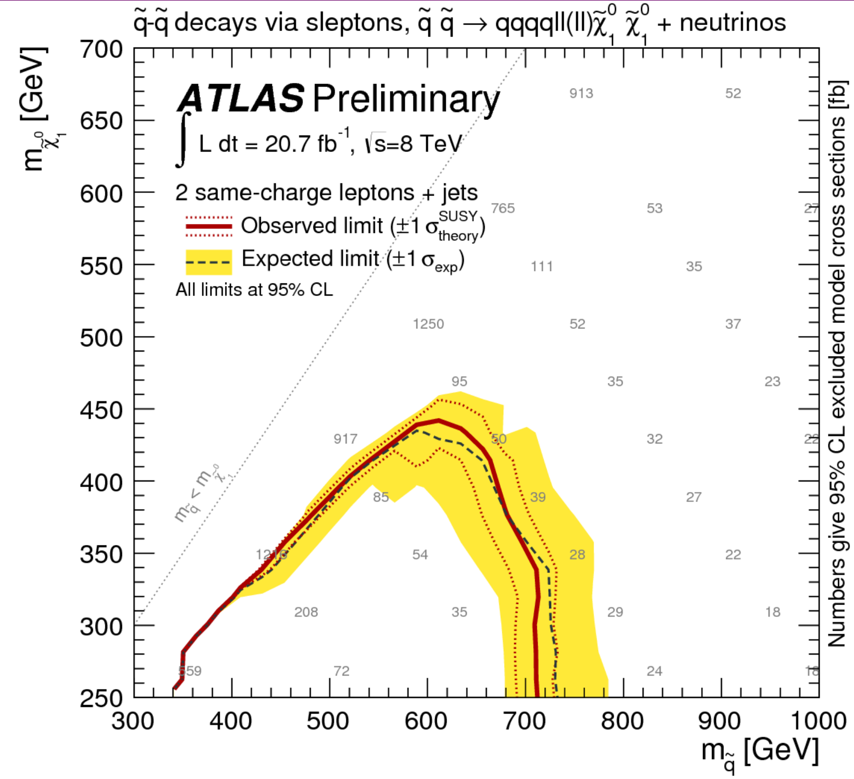
Exclusion limit:
on m($\tilde{g}$) is 1000 - 1100 GeV for m($\tilde{\chi}_1^0$) up to 650 GeV

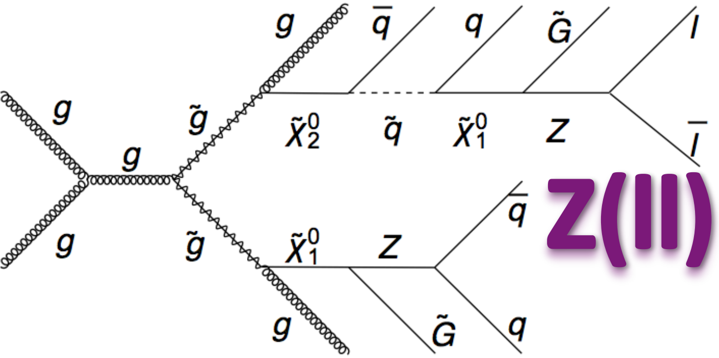


Direct-squarks (via sleptons):
- direct squark pair production (1st and 2nd generation)

$$\tilde{q} \rightarrow q'\,\tilde{\chi}_1^{\pm} \hookrightarrow \tilde{\ell}\nu, \ell\tilde{\nu}$$
$$\tilde{q} \rightarrow q\,\tilde{\chi}_2^0 \hookrightarrow \tilde{\ell}\ell, \tilde{\nu}\nu$$

Exclusion limit:
on m($\tilde{q}$) is 600 – 660 GeV for m($\tilde{\chi}_1^0$) below 380 GeV





Z(ll) + jets + EtMiss

√s = 8 TeV

L = 5.8 fb^{-1}

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Opposite-sign ee or μμ + jets + EtMiss

Interpretation and limits in the context of GGM with:

NLSP = Higgsino-like lightest neutralino

- tanß = 1.5 $\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$
- tanß = 30 $\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$
  $\rightarrow h\tilde{G}$

Event Selection

Z(ll) + jets + EtMiss

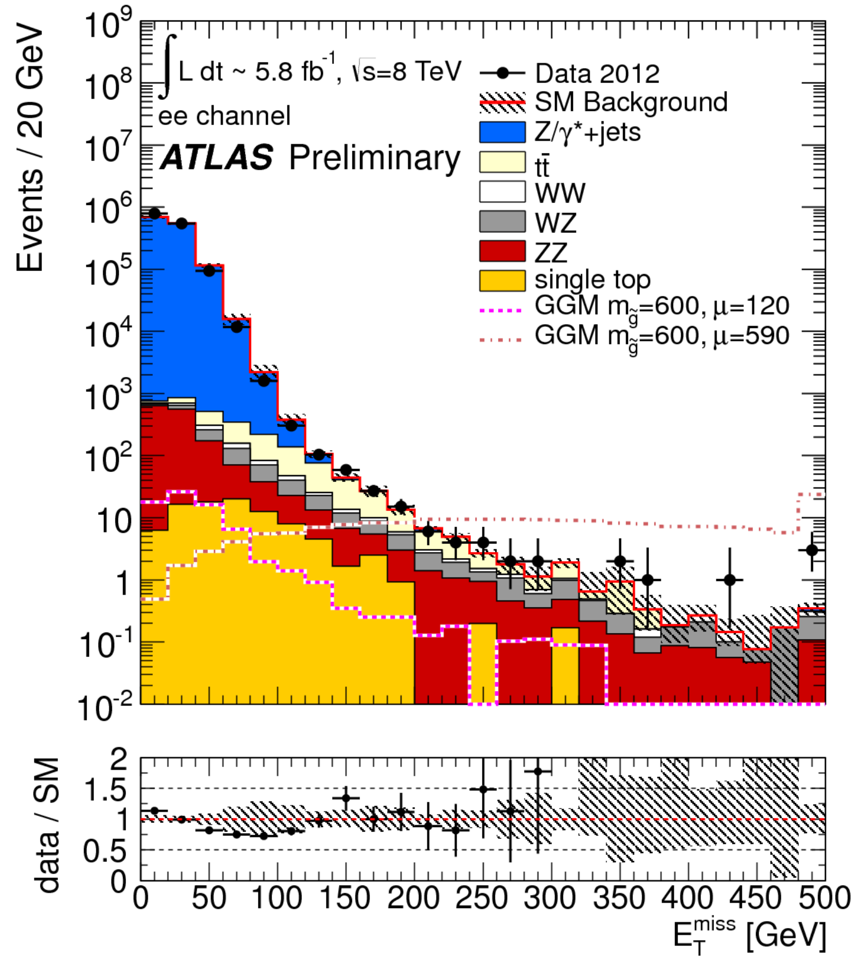
Z preselection:

- Triggers:
  - ee, μμ, eμ
- Two same-flavor, oppositely-charged signal leptons
  - Leading lepton pT > 25 GeV
- Invariant mass: 81 < mll < 101 GeV

Signal Regions (after Z preselection):

Signal Region	SR1	SR2
E_T^{miss}[GeV]	>220	>140
Leading jet p_T[GeV]	>80	-
Second jet p_T[GeV]	>40	-
Third jet p_T[GeV]	>40	-
H_T[GeV]	-	>300

EtMiss after Z(ee) preselection



For definitions of variables go to backup slide 26

Background Estimation

Z(ll) + jets + EtMiss

QCD and inclusive **W+jets** negligible

WZ, ZZ background
Estimated from MC

SM backgrounds:
- QCD and inclusive W+jets
- WZ, ZZ
- top, WW, Z(ττ); top = ttbar + Wt
- Z + jets

top, WW, ττ background

$$BR\left[(WW,top,\tau\tau)\to\begin{Bmatrix}ee\\ \mu\mu\end{Bmatrix}\right]=\frac{1}{2}BR\left[(WW,top,\tau\tau)\to e\mu\right]$$

Basic idea: $N_{ee}^{SR}=N_{\mu\mu}^{SR}=\frac{1}{2}N_{e\mu}^{SR}$

(simplified version of the method)

In the complete version of the method other factors taken into account: different reconstruction efficiency of electrons and muons, …

Background Estimation

Z(ll) + jets + EtMiss

SM backgrounds:
- QCD and inclusive W+jets
- WZ, ZZ
- top, WW, Z(ττ); top = ttbar + Wt
- **Z + jets**

Z + jets background

Jet smearing method:

Signal: Z + jets + EtMiss → from LSP

(Instrumental) bkg: Z + jets + fake Etmiss → from mis-measurement of jets

Estimating number of events in SR with high fake Etmiss ⇨ Estimating of number of Z + jets bkg events in SR

How do we estimate the number of events with high fake EtMiss?

SEED REGION	×	**RESPONSE FUNCTION**	=	**PSEUDO-DATA**
region with well measured jets => low EtMiss region		modeling the response of the calorimeters		simulation of events with no real EtMiss after passing throught the calorimeter

Applying SR cuts to pseudo-data => Estimation of number of Z + jets bkg events in SR

√s = 8 TeV
L = 5.8 fb^{-1}

Results

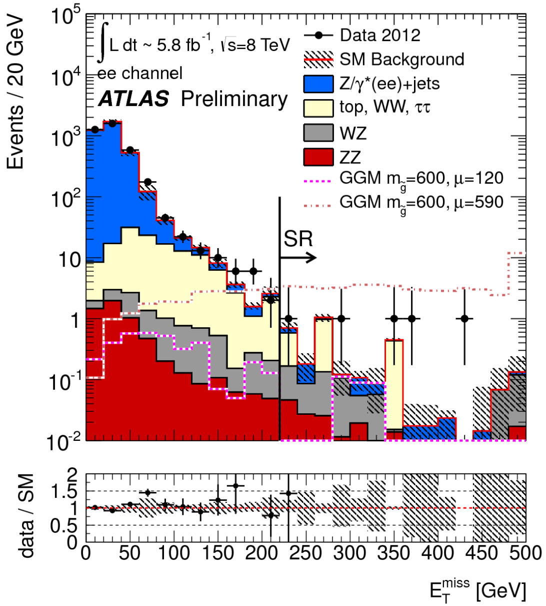
Z(ll) + jets + EtMiss

	SR1	
	ee	*μμ*
Total SM Background	3.1 ± 1.1(stat.) ± 0.5(syst.)	3.2 ± 1.3(stat.) ± 0.4(syst.)
Observed	5	5
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (exp) [fb]	1.3	
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (obs) [fb]	2.0	

Expected bkg events
Observed data events
Upper limits on visible cross sections from models of physics beyond the SM

	SR2	
	ee	*μμ*
Total SM Background	55.9± 3.9(stat.) ± 8.4(syst.)	59.5± 4.4(stat.) ± 10.4(syst.)
Observed	66	61
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (exp) [fb]	6.3	
$\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (obs) [fb]	7.7	

Expected bkg events
Observed data events
Upper limits on visible cross sections from models of physics beyond the SM



SR1 ee

NO SIGNIFICANT EXCESS IN ANY OF THE SIGNAL REGIONS

Results

GGM
SR1

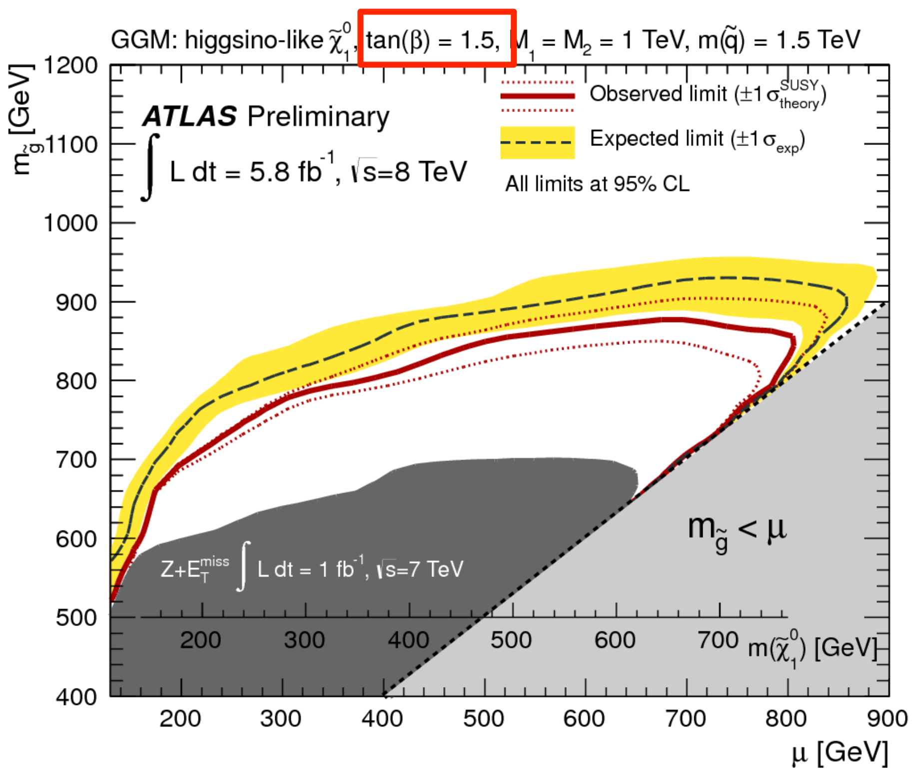
Z(ll) + jets + EtMiss

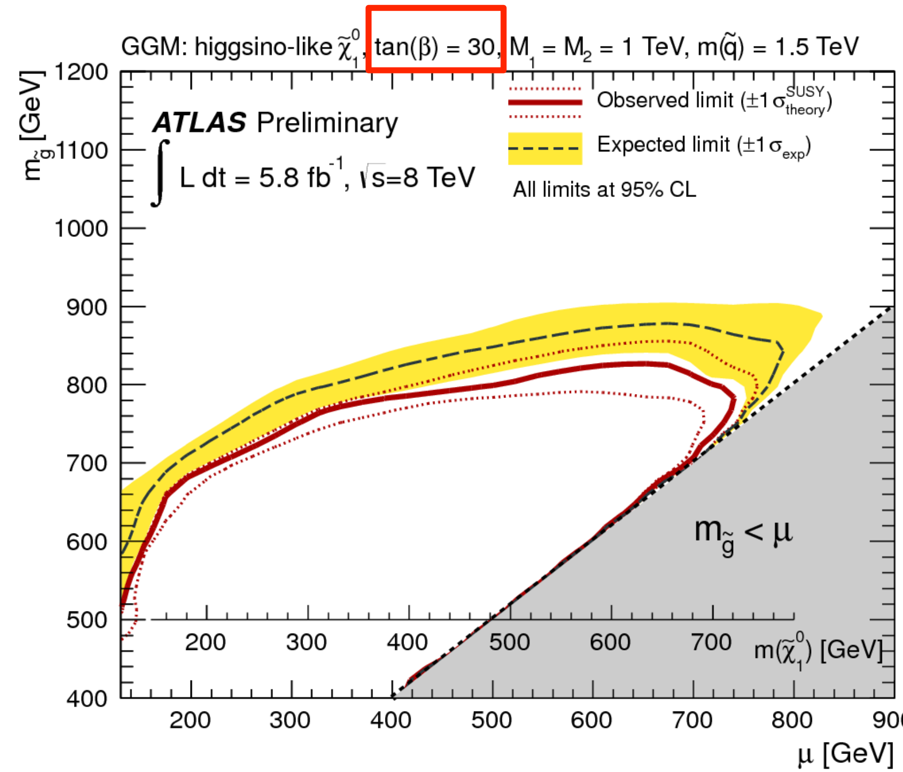
GGM (General Gauge Mediation)

- LSP = gravitino
- **NLSP = Higgsino-like lightest neutralino** ($c\tau_{NLSP}$ = 0.1 mm)

Exclusion limits:

- tanß = 1.5 => m(gluino) up to 680 – 880 GeV for μ in the range 180-800 GeV
- tanß = 30 => m(gluino) up to 680 – 820 GeV for μ in the range 180-740 GeV





Summary

- Inclusive searches for squarks and gluinos are a very powerful tool to test a large set of SUSY models.
- Three different inclusive searches have been presented:
  - ✓ 1/2 taus + jets + EtMiss
  - ✓ 2 same-sign leptons + 0-3 b-jets + EtMiss
  - ✓ Z(ll) + jets +EtMiss
- Result have been interpreted in several SUSY models (compatible with the discovered Higgs-like boson whenever possible) giving rise to exclusion limits.
- No evidence of new Physics beyond the SM has been observed for the moment but… still a lot of results will come.

BACKUP

Variables Definitions

1-2 taus + jets + EtMiss

Transverse mass: $m_{\mathrm{T}}^{\tau} = \sqrt{2 p_{\mathrm{T}}^{\tau} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\Delta\phi(\tau, E_{\mathrm{T}}^{\mathrm{miss}})))}$

Scalar sum: $H_{\mathrm{T}} = \sum p_{\mathrm{T}}^{\tau} + \sum_{i=1,2} p_{\mathrm{T}}^{jet_i}$

Effective mass: $m_{\mathrm{eff}} = H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$

2 SS lept + 0-3 b-jets

Transverse mass: $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{l} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\Delta\phi(l, E_{\mathrm{T}}^{\mathrm{miss}})))}$

Effective mass: $m_{eff} = \sum_{i} p_{\mathrm{T}}^{l_i} + \sum_{i=1,2} p_{\mathrm{T}}^{jet_i} + E_{\mathrm{T}}^{\mathrm{miss}}$

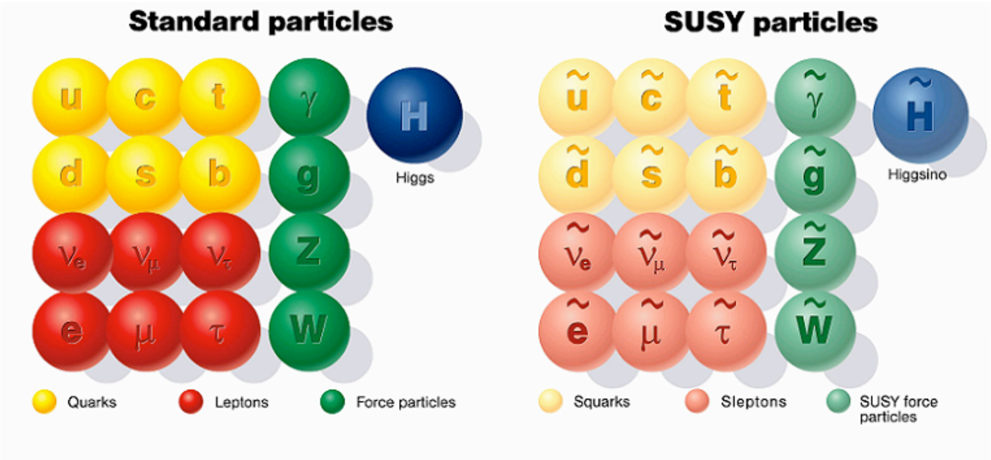
Z(ll) + jets + EtMiss

Scalar sum: $H_{\mathrm{T}} = \sum_{i} p_{\mathrm{T}}^{lepton_i} + \sum_{i=1,2} p_{\mathrm{T}}^{jet_i}$

Effective mass: $m_{\mathrm{eff}} = H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$

Supersymmetry

- SUSY = global symmetry between fermions & bosons
  - all SM particles have SUSY-partners with spin difference of ±1/2
- Theoretical motivation
  - Higgs mass stabilisation against loop corrections (fine-tuning problem)
  - unification of gauge couplings at single scale
  - dark matter candidate: Lightest supersymmetric particle (LSP)



SUSY Models

mSUGRA/CMSSM Parameters

- → gravity-mediated SUSY breaking
- m_0: mass of scalar particles
- $m_{1/2}$: gaugino masses
- A_0: trilinear Higgs-sfermion-sfermion coupling parameter
- $\tan\beta = \nu_u/\nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter μ

GMSB Parameters

- → gauge-mediated SUSY breaking
- Λ: SUSY breaking mass scale felt by the low-energy sector
- M_{mes}: mass scale of the messenger fields
- N_5: number of SU(5) messenger fields
- C_{grav}: scale factor of the gravitino coupling
- $\tan\beta = \nu_u/\nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter μ

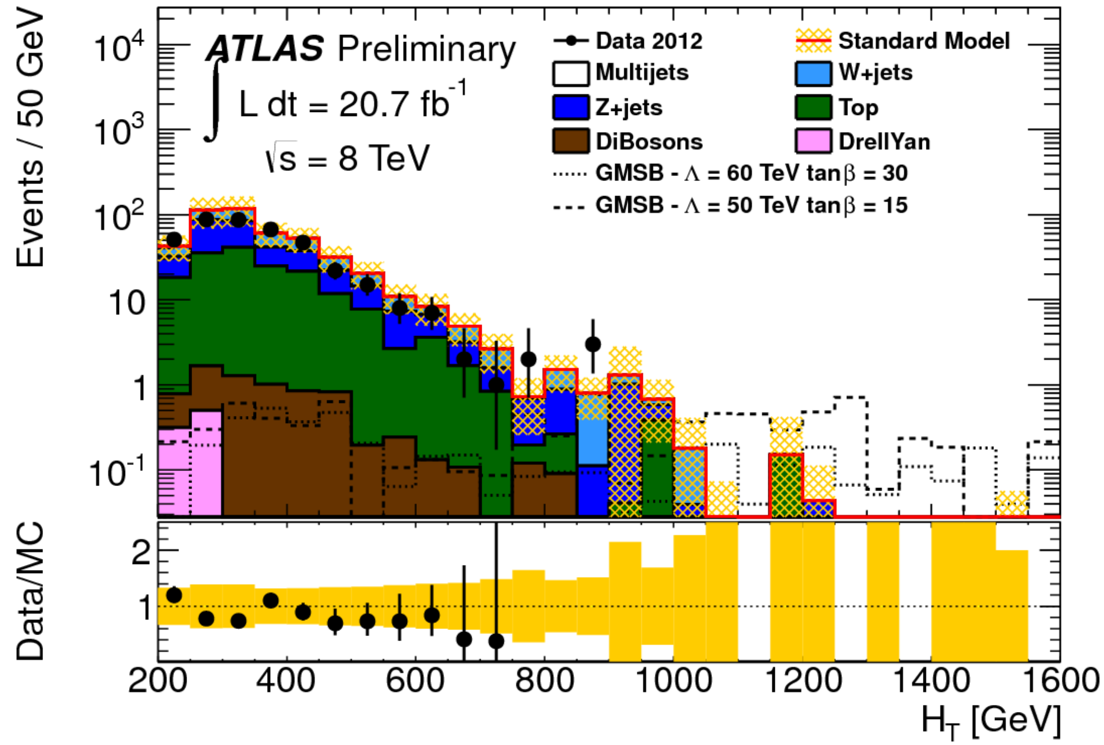
NGM

- starts from General Gauge Mediation
- GGM: no specific SUSY mass hierarchy is predicted for colored and uncolored states
  ⇒ gluinos and squarks can be below the TeV scale = within reach of LHC
- NGM: decouple all sparticles not related to fine-tuning of Higgs sector
  ⇒ light stop and light gluino as only light (relevant) coloured sparticle
- some additional mechanism needed (as in GMSB) to produce “correct” Higgs mass

Background Estimation

1-2 taus + jets + EtMiss

- Dominant backgrounds to the **1τ SR**:
  - Z + jets
  - W + jets
  - top
- Events divided into those in which:
  - a true tau exists
  - a jet is misidentified as a tau (fake tau)
- Since the composition of true and fake taus in the CR and SR may differ => necessary to measure separate scaling factors for the two cases



H_T distribution after applying all SR cuts except the H_T one.

Background Estimation

1-2 taus + jets + EtMiss

- Background Control Regions (**CRs**) **used to estimate the** yield of **background** candidates **in the 1τ SR**

top (true + fake)	W+jets (true)	W/Z+jets (fake)
$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad $m_T^\tau < 80$ GeV (true τ) *or* 80 GeV $< m_T^\tau < 130$ GeV (fake τ) $E_T^{miss}/m_{eff} > 0.3$ $N_{b-tag} \geq 1$ SF ~ 1 (true τ), SF ~ 0.6 (fake τ)	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad $m_T^\tau < 80$ GeV $E_T^{miss}/m_{eff} > 0.3$ $\Delta\phi(\tau, E_T^{miss}) > 0.2$ $N_{b-tag} = 0$ SF ~ 0.9	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad 80 GeV $< m_T^\tau < 130$ GeV $E_T^{miss}/m_{eff} > 0.3$ $N_{b-tag} = 0$ SF ~ 0.7

Z+jets	Multijets	
2 opposite sign μ ($p_T > 15$ GeV, $\lvert\eta\rvert < 2.4$) ≥2 jets (130 GeV, 30 GeV) a tau with $p_T > 20$ GeV 82 GeV$< m_{\mu^+\mu^-} < 100$ GeV	ABCD method	

Scaling Factor = (SF)

Background Estimation

1-2 taus + jets + EtMiss

- Background Control Regions (**CRs**) **used to estimate the** yield of **background** candidates **in the 1τ SR**

No Z+jets (true) CR

because:

- in Z+jets events in the SR, the Z decays always to neutrinos
- => the τ candidate is always a mis-identified jet (always a fake τ)

W/Z+jets (fake)

$$\Delta(\phi_{jet_{1,2}-\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}}) > 0.3 \text{ rad}$$
$$80\,\mathrm{GeV} < m_{\mathrm{T}}^{\tau} < 130\,\mathrm{GeV}$$
$$E_{\mathrm{T}}^{\mathrm{miss}}/\mathrm{m_{eff}} > 0.3$$
$$N_{\mathrm{b-tag}} = 0$$

Z+jets

2 opposite sign μ

$(p_{\mathrm{T}} > 15\,\mathrm{GeV},\ |\eta| < 2.4)$

≥ 2 jets (130 GeV, 30 GeV)

a tau with $p_T > 20$ GeV

$82\,\mathrm{GeV} < m_{\mu^+\mu^-} < 100\,\mathrm{GeV}$

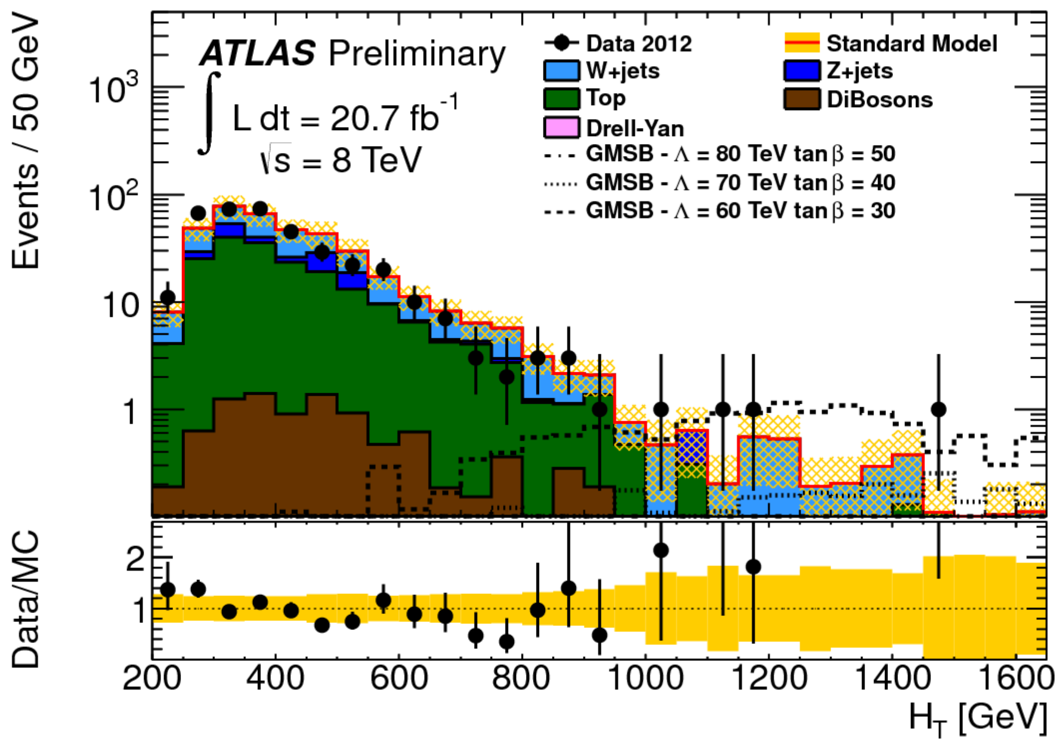
This CR is used only as a cross check of the other one. Good agreement is obtained between both

Background Estimation

1-2 taus + jets + EtMiss

- Dominant backgrounds to the **2τ SRs**:
  - Z + jets
  - W + jets
  - top
- W and top backgrounds dominated by events where:
  - 1 tau candidate is a true tau
  - the others a fake
- Z+jets events dominated by final states with Z -> ττ decays

True and fake tau canditates composition is the same in the CR and SR. No need to separate CRs in true or fake dominated



H_T distribution after applying all 2τ GMSB SR cuts except the H_T one.

Background Estimation

1-2 taus + jets + EtMiss

- Background Control Regions (**CRs**) **used to estimate the** yield of **background** candidates **in the** **2τ GMSB SR**

top	W+jets	Z+jets
$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad $m_T^{\tau 1} + m_T^{\tau 2} \geq 150$ GeV $H_T < 550$ GeV $N_{b-tag} \geq 1$ SF ~ 0.6	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad $m_T^{\tau 1} + m_T^{\tau 2} \geq 150$ GeV $H_T < 550$ GeV $N_{b-tag} = 0$ SF ~ 0.8	$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) > 0.3$ rad $m_T^{\tau 1} + m_T^{\tau 2} < 80$ GeV $H_T < 550$ GeV SF ~ 1.1

Multijets

$\Delta(\phi_{jet_{1,2}-\mathbf{p}_T{}^{miss}}) < 0.3$ rad

$E_T^{miss}/m_{eff} < 0.4$

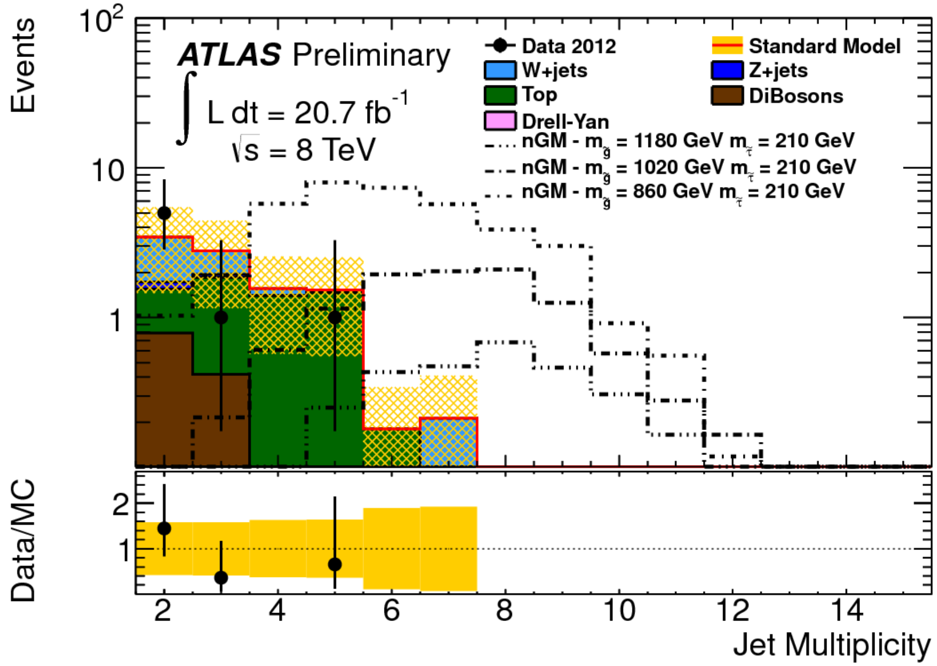
Scaling Factor = (SF)

Background Estimation

1-2 taus + jets + EtMiss

- Background Control Region (**CR**) **used to estimate the** yield of **background** candidates **in the 2τ nGM SR**

Top events are the overall dominant background and therefore only one CR is defined



Jet multiplicity distribution after applying all 2τ nGM SR cuts except the n_jets one.

Results

mSUGRA/cMSSM

1τ analysis

1-2 taus + jets + EtMiss

yellow band ➔ 1σ statistical and systematic uncertainties on the expected background

dashed red lines ➔ influence of the theoretical uncertainties on the signal cross section on the limit

Results

1-2 taus + jets + EtMiss

nGM (natural Gauge Mediation)

Constructed starting from GGM

Assumptions and choice of parameters for this analysis:

- gluino is the only light coloured sparticle
- $\mu \ll M_1$ (bino mass), M_2 (wino mass)
- $m_{squarks} = m_{sleptons} = M_1 = M_2 = 2.5$ TeV except the stau mass
- all trilinear couplings = 0

Imply:

NLSP = stau

Example of gluino decay mode

$$\tilde{g} \to g\tilde{\chi}_i^0 \to g\tau\,\tilde{\tau} \to g\tau\tau\tilde{G}, \text{ with } i = 1, 2$$

Exclusion limit:

- on the **mass(gluino)** is **1140 GeV**

Event Selection

2 SS lept + 0-3 b-jets

- 3 Signal Regions (SR) optimized to maximize the sensitivity to different SUSY models:

Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV $m_T > 100$ GeV, $m_{eff} > 400$ GeV	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, binned shape fit in m_{eff} for $m_{eff} > 300$ GeV
SR1b	≥1	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV $m_T > 100$ GeV, $m_{eff} > 700$ GeV	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, binned shape fit in m_{eff} for $m_{eff} > 300$ GeV
SR3b	≥3	$N_{jets} \geq 4$ -	$N_{jets} \geq 5$, $E_T^{miss} < 150$ GeV or $m_T < 100$ GeV

For definitions of variables go to backup slide 26

Background Estimation

2 SS lept + 0-3 b-jets

- Dominant backgrounds:
  - Real isolated SS lepton pairs
    - Arise mainly from:
      - ttbar (at least one t decays leptonically) + W/Z (decaying leptonically)
      - dibosons (WZ, ZZ)
    - Estimated from MC
  - Mis-measurement of the lepton charge:
    - Dominant mechanism of charge mis-identification:
      - radiation of a hard photon bremsstrahlung followed by an asymmetric conversion for which the e with the opposite charge dominates $e^{\pm} \rightarrow e^{\pm}\gamma \rightarrow e^{\pm}e^{\pm}e^{\mp}$
      - mainly from Z/γ*, ttbar
    - Estimated with fully data-driven technique
  - fake leptons: 1 real lepton + 1 fake lepton
    - Arise mainly from:
      - ttbar events (one lepton comes from the decay of a b-hadron and the other from one of the W bosons)
      - Estimated from data.

Results

2 SS lept + 0-3 b-jets

lightest neutralino = LSP

mSUGRA/CMSSM:
described on slide

Gluino-squark (via W):

- gluino-gluino production
- m(chargino) = 2m(neutralino)
- final states: 4 light jets+ 2 W + 2 LSPs + 0 b-jets

Exlusion limit: on m(gluino) is 750-830 GeV for m (LSP) up to 450 GeV

Gluino-squark (via sleptons):

- gluino-gluino production
- m(chargino1) = m(neutralino2) = average of m(gluino) and m(LSP)
- m(slepton) = m(sneutrino) = average of m(chargino1) and m(LSP) (3 flavours considered)
- m(squarks) >> m(gluino)
- final states: 4 light jets + up to 4 charged leptons + EtMiss

Exclusion limit: on m(gluino) is 1000 - 1100 GeV for m(LSP) up to 650 GeV

Direct-squarks (via sleptons):

- direct pair production of squarks (1st and 2nd generation only)
- same mass assignments as in Gluino-squark via sleptons
- Final states: 2 light jets + up to 4 charged leptons + EtMiss

Exclusion limit: on m(squark) is 600 – 660 GeV for m(LSP) below 380 GeV

Overview of the Method

$N_{ee}^{est}, N_{\mu\mu}^{est} \equiv$ estimated number of events in the **ee** and **μμ** channels **from** the **WW, ttbar, Wt and tautau** processes **in the SRs**

New names in the note: **CR-DF = same cuts than in SR but for eμ channel**

$$N_{e\mu}^{data,corr} = N_{e\mu}^{data} - N_{e\mu}^{MC,sub}$$

$N_{e\mu}^{data} \equiv$ number of eμ events observed in the CR-DFs

$N_{e\mu}^{MC,sub} \equiv$ number of events from WZ, ZZ, W+jets and Z+jets estimated from MC

$$N_{ee}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{ee} \qquad k_{ee} = \sqrt{\frac{N_{ee}^{\text{data}}}{N_{\mu\mu}^{\text{data}}}}$$

$$N_{\mu\mu}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{\mu\mu} \qquad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{\text{data}}}{N_{ee}^{\text{data}}}}$$

Overview of the Method

$$k_{ee} = \sqrt{\frac{N_{ee}^{data}}{N_{\mu\mu}^{data}}}, \quad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{data}}{N_{ee}^{data}}} \quad \longrightarrow$$

these factors take into account the differences between the electron and muon reconstruction efficiencies

$N_{ee}^{data}, N_{\mu\mu}^{data} \equiv$ numbers of ee and μμ events from data in each of the CRs

CRs = SRs after inverting the E_T^{miss} cut

$$N_{ee}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{ee} \qquad k_{ee} = \sqrt{\frac{N_{ee}^{\text{data}}}{N_{\mu\mu}^{\text{data}}}}$$

$$N_{\mu\mu}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{\mu\mu} \qquad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{\text{data}}}{N_{ee}^{\text{data}}}}$$

Common object definitions

Representative object definitions used by the ATLAS SUSY Working Group

1. Jets: Built from calorimeter clusters using the anti-k_t association scheme with radius parameter $R = 0.4$, and calibrated to correct for dead material, calorimeter response, pile-up etc. Analyses use jets with $|\eta| < 2.8$ and varying thresholds on p_T and the fraction of tracks originating from the primary vertex (JVF), whereas all jets with $|\eta| < 4.9$ and $p_T > 20$ GeV enter $\not{E}_T$.
2. Muons: Identified as ID tracks combined with MS track segments, with $p_T > 10$ GeV and $|\eta| < 2.4$. "Signal" muons have $p_T > 20$ GeV and have higher object quality and isolation requirements.
3. Electrons: Identified as ID tracks combined with calorimeter clusters, with $p_T > 20$ GeV and $|\eta| < 2.47$. "Signal" electrons have $p_T > 25$ GeV and have higher object quality and isolation requirements.
4. Photons: Identified on the basis of shower shape in the calorimeter or from conversion tracks, with $p_T > 20$ GeV, $|\eta| < 2.37$ and $(1.52 < |\eta|$ or $1.37 > |\eta|)$. Additional "ambiguity resolution" criteria reduce contamination from electrons. A transverse energy isolation requirement of < 5 GeV is imposed in a narrow cone of $\Delta R < 0.2$.
5. Tau jets: Identified using a multivariate discriminator (BDT) taking into account track information and calorimeter shower shapes, with $p_T > 20$ GeV, $|\eta| < 2.5$ and containing 1 or 3 tracks of $p_T > 1$ GeV and with a charge sum of ± 1.
6. b-jets: Identified using multivariate discriminators taking into account impact parameter and secondary vertex information.

ATLAS SUSY Search Strategy

- **Use a basic Cut & Count approach**
- **Define Signal Region(s) (SR) for various topologies of squarks and gluinos decays:**
  - Use quantities that can help to discriminate signal from the SM backgrounds:
    - ✓ EtMiss (transverse missing energy), jet multiplicity, scalar pT sum of final objects, effective mass, transverse mass.
- **Background determination:**
  - QCD multijets backgrounds: data-driven
  - <u>Major backgrounds: semi data-driven</u>:
    - ✓ Define a control region (CR) for each of the backgrounds to test MC performance
    - ✓ Control region kinematically close to signal region (take into account signal contamination)
    - ✓ Normalise MC yields to data
    - ✓ Transfer factor from CR to SR subtracting other backgrounds in the region (these calculations are done with MC)
    - ✓ Systematics reduced due to ratio SR/CR
  - <u>Minor backgrounds: MC-only estimation</u>
- **Discovery/Exclusion fit:**
  - CLs exclusion limits or discovery