SUSY searches with photon and tau signatures

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SUSY 15
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Introduction

An overview of ATLAS SUSY searches targeting final states with photons and taus

- **Considering R-parity conserving models with large E_T^{miss} signatures**
- **Promptly decaying sparticles**
- **Strong production is the main focus, for more on:**
  - **Electroweak** see talk by Christopher Bock
  - **Third generation** see talk by Pierfransesco Butti
- **All results using the full 2012 8 TeV 20.3 fb^{-1} dataset**
- **The analyses are particularly motivated in the context of gauge-mediated symmetry breaking, where the LSP is a gravitino**

The following final states are covered:

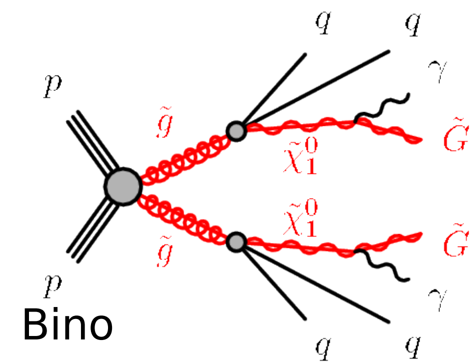
- **Two photons / Photon + jets/e/mu** — **1507.05493**
- **Higgs to photon + E_T^{miss}** — **ATLAS-CONF-2015-001**
- **One tau / two taus / taus plus e/mu** — **1407.0603**
  Summary paper — **1507.05525**

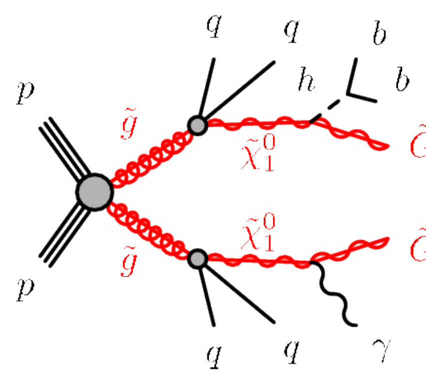
CERN-PH-EP-2015-168

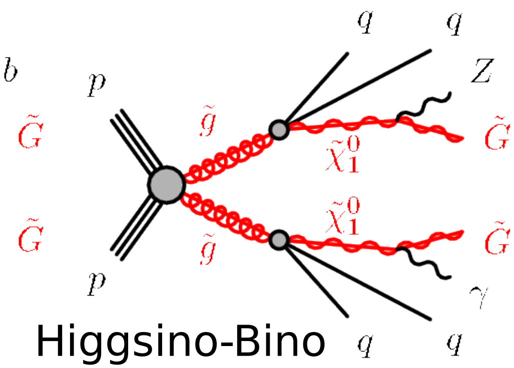
Photons + Etmiss Analysis overview

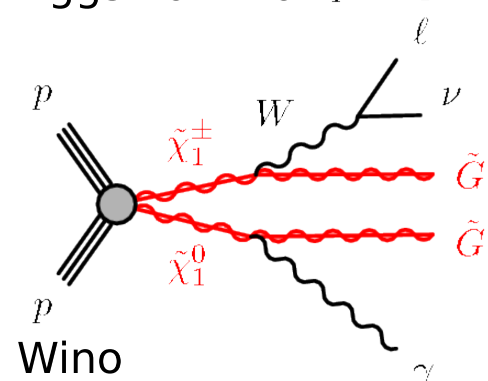
The analysis targets processes in the **GGM model**

- Strong and electroweak production considered
- Decay chains largely determined by the NLSP
- Each channel focused on a specific NLSP type
- Further split for high- and low-mass NLSP









Event selection:

	Channel	Trigger	Target NLSP
1)	> 1 photon	two photon trigger	Wino-bino
2)	> 0 photon plus **b-jet**	single photon trigger	Higgsino-bino
3)	= 1 photon plus **multiple jets**	single photon trigger	Higgsino-bino
4)	> 0 photon plus **electron/muon**	single photon trigger	Wino

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Selection
Diphoton and photon + (b-)jet

Signal Region	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-L}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-H}}$	$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-L}}$	
BWH				
No. photons (E_T [GeV])	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 250	> 150	> 200
H_{T} [GeV]	–	–	> 600	> 400
m_{eff} [GeV]	> 1800	> 1500	–	–
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$ (No. leading jets)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)
$\Delta\phi_{\mathrm{min}}(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	–	> 0.5	–	> 0.5

Higher energy scale in SUSY events

$E_{\mathrm{T}}^{\mathrm{miss}}$ well reconstructed

Signal Region	$\mathrm{SR}^{\gamma b}_{\mathrm{L}}$	$\mathrm{SR}^{\gamma b}_{\mathrm{H}}$	$\mathrm{SR}^{\gamma j}_{\mathrm{L}}$	$\mathrm{SR}^{\gamma j}_{\mathrm{H}}$
No. photons (E_{T} [GeV])	> 0 (> 125)	> 0 (> 150)	1 (> 125)	1 (> 300)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	> 200	> 200	> 300
H_{T} [GeV]	–	> 1000	–	> 800
No. jets (No. b-jets)	$2-4$ (> 1)	> 3 (> 0)	$> 3^{a}$	$> 1^{a}$
No. leptons	0	–	0	0
M_{bb} [GeV]	$75-150$	–	–	–
$M_{\mathrm{T}}^{\gamma, E_{\mathrm{T}}^{\mathrm{miss}}}$ [GeV]	> 90	> 90	–	–
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$ (No. leading jets)	> 0.3 (2)	> 0.3 (4)	> 0.4 (2)	> 0.4 (2)
R_{T}^{4}	–	–	< 0.85	
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, \gamma)$	–	–	–	< 2.0

ttbar

W → e ν (e misreconstructed)

Softer n_{jet} spectrum in SM

Selection
Photon + lepton

Signal Region	$SR_e^{\gamma\ell}$	$SR_\mu^{\gamma\ell}$	
No. photons (E_T [GeV])	> 0 (> 125)	> 0 (> 125)	
E_T^{miss} [GeV]	> 120	> 120	
H_T^{jets} [GeV]	< 100	< 100	ttbar
No. leptons	> 0 (e)	> 0 (μ)	
$\lvert M_{e\gamma} - M_Z \rvert$ [GeV]	(> 15)	–	Z → e e
$M_T^{\ell, E_T^{miss}}$ [GeV]	> 120	> 120	W → ℓ ν / ttbar
$\Delta R(\ell, \gamma)$	> 0.7	> 0.7	

Many different SRs covering a wide range of models and NLSP masses

Background estimation

The main analysis backgrounds in all SRs come from

- Associated production of **real photons** with vector bosons or top and **E_T^{miss} from neutrinos**
- Jets or electrons **misidentified as photons**
- QCD events with real photons and E_T^{miss} from **instrumental effects**

For these main backgrounds data-driven estimates are made, to decrease systematic uncertainties

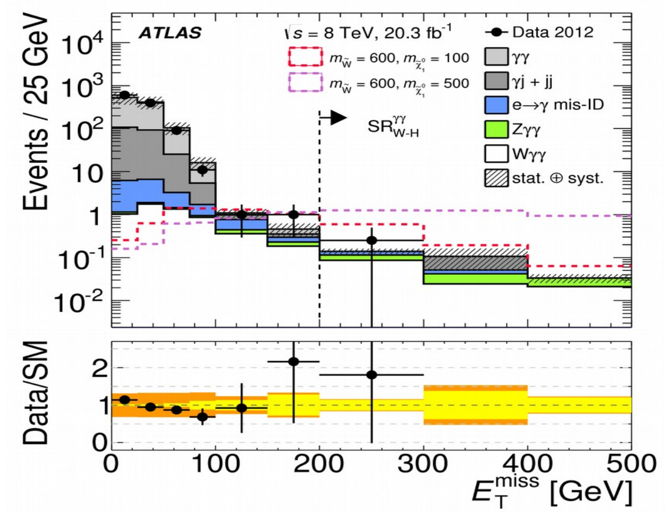
Significant variation in background estimation regions used between channels, due to different selections

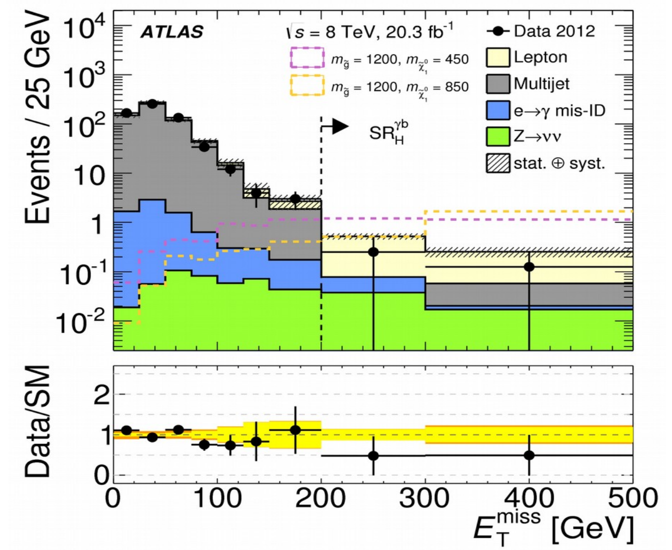
Results

No significant excess above SM expectation observed in any of the 10 signal regions

- **Largest excess seen in photon + electron channel, 6% probability of such excesses**
- **Limits on maximum number of events expected in each SR as well as the upper limit on the cross section set**

Signal region	$N_{\rm obs}$	$N_{\rm exp}^{\rm SM}$	$S_{\rm obs}^{95}$	$\langle\epsilon\sigma\rangle_{\rm obs}^{95}$[fb]	$\langle\epsilon\sigma\rangle_{\rm exp}^{95}$[fb]
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-L}}$	0	$0.06^{+0.24}_{-0.03}$	3.0	0.15	0.15 ± 0.01
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{S-H}}$	0	$0.06^{+0.24}_{-0.04}$	3.0	0.15	0.15 ± 0.01
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-L}}$	5	$2.04^{+0.82}_{-0.75}$	8.2	0.41	$0.25^{+0.09}_{-0.06}$
$\mathrm{SR}^{\gamma\gamma}_{\mathrm{W-H}}$	1	$1.01^{+0.48}_{-0.42}$	3.7	0.18	$0.18^{+0.07}_{-0.02}$
$\mathrm{SR}^{\gamma b}_{\mathrm{L}}$	12	18.8 ± 5.4	8.1	0.40	$0.57^{+0.24}_{-0.16}$
$\mathrm{SR}^{\gamma b}_{\mathrm{H}}$	2	3.82 ± 1.25	4.0	0.20	$0.27^{+0.09}_{-0.07}$
$\mathrm{SR}^{\gamma j}_{\mathrm{L}}$	2	1.27 ± 0.43	5.5	0.27	$0.19^{+0.10}_{-0.06}$
$\mathrm{SR}^{\gamma j}_{\mathrm{H}}$	2	0.84 ± 0.38	5.6	0.28	$0.20^{+0.11}_{-0.05}$
$\mathrm{SR}^{\gamma \ell}_{e}$	16	10.5 ± 1.4	14.2	0.70	$0.41^{+0.20}_{-0.12}$
$\mathrm{SR}^{\gamma \ell}_{\mu}$	10	14.1 ± 1.5	6.0	0.30	$0.45^{+0.21}_{-0.14}$





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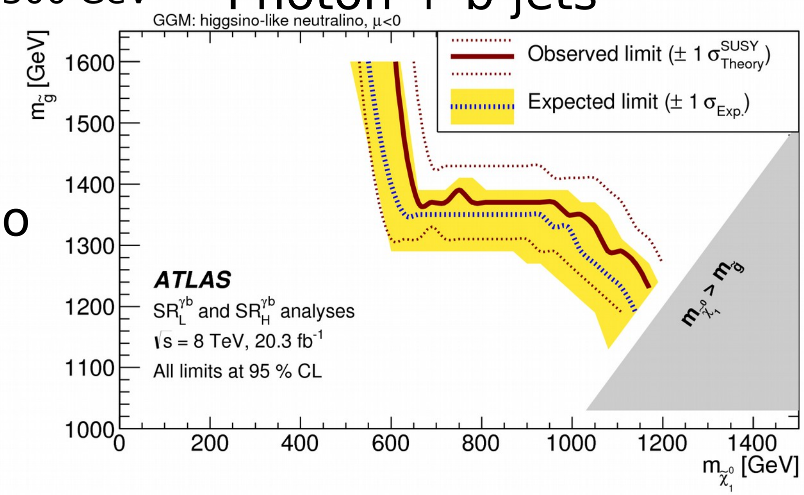
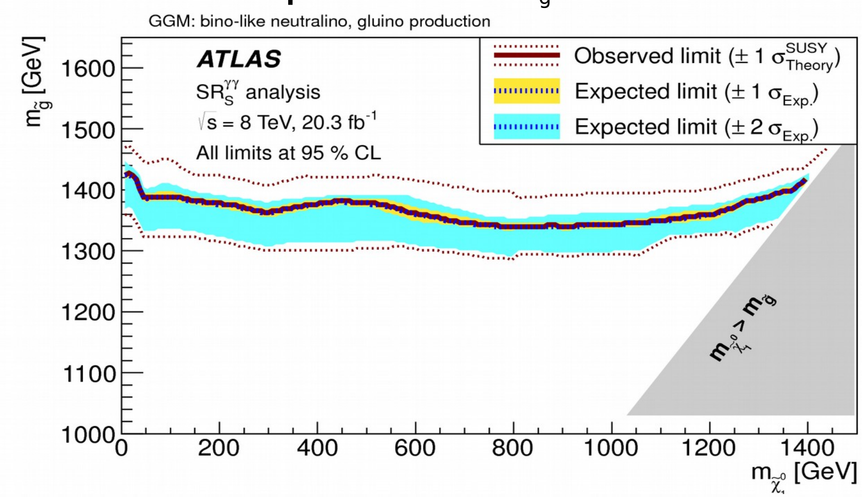
Interpretation

M_g > 1300 GeV Photon + b-jets

Higgsino NLSP

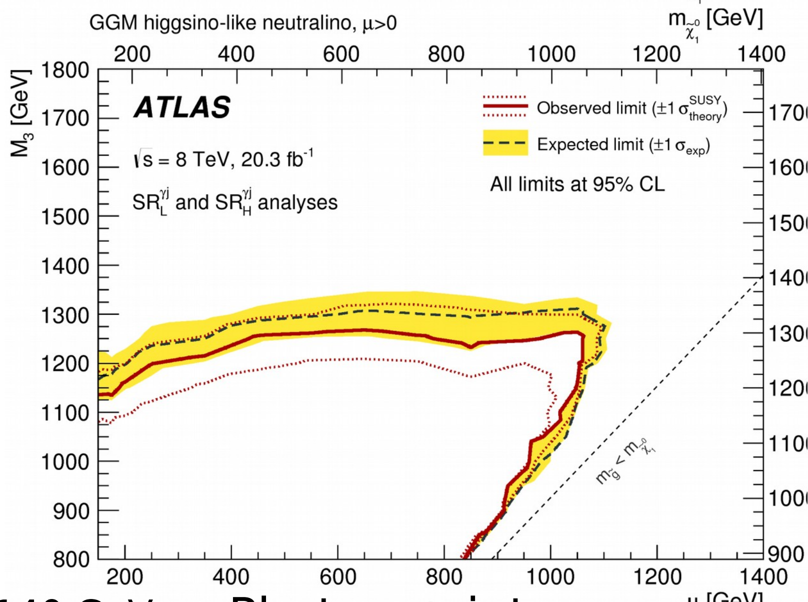


Diphoton M_g > 1290 GeV

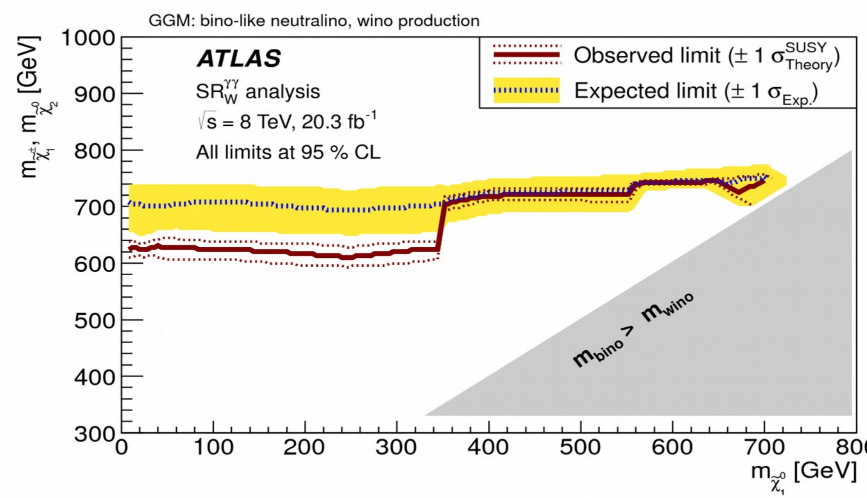


Bino NLSP

Higgsino NLSP



Bino NLSP

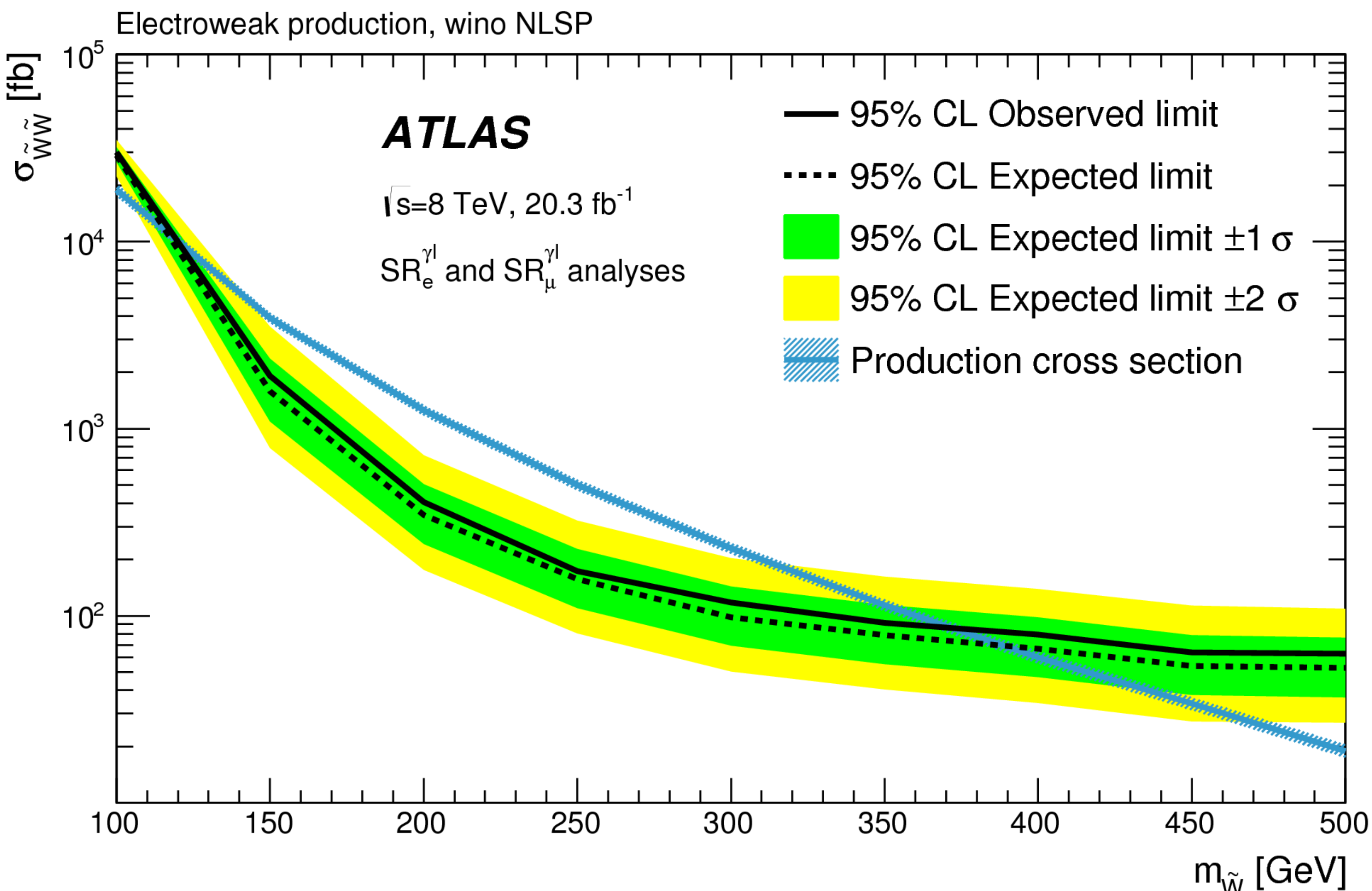


M_3 > 1140 GeV Photon + jets

Diphoton M_{wino} > 590 GeV

Interpretation

Photon + lepton



Excluded: 124 GeV < $M_{\tilde{W}}$ < 361 GeV

Higgs to photon + E_T^{miss}

In GMSB and NMSSM models the following processes can take place

1) $h \rightarrow \tilde{\chi}^0_1/\tilde{\chi}^0_2\ \tilde{G}/\tilde{\chi}^0_1 \rightarrow \gamma\ \tilde{G}/\tilde{\chi}^0_1\ \tilde{G}/\tilde{\chi}^0_1$

2) $h \rightarrow \tilde{\chi}^0_1/\tilde{\chi}^0_2\ \tilde{\chi}^0_1/\tilde{\chi}^0 \rightarrow \gamma\ \gamma\ \tilde{G}/\tilde{\chi}^0_1\ \tilde{G}/\tilde{\chi}^0_1$

Signature: Etmiss + photon

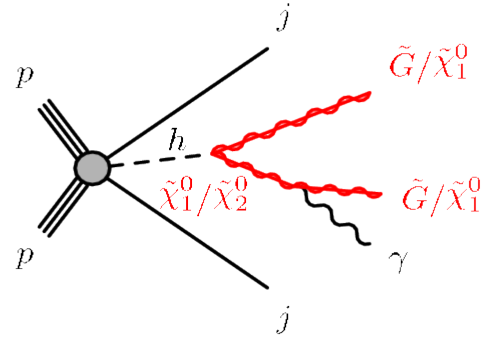
→ **Trigger: Photon + Etmiss**

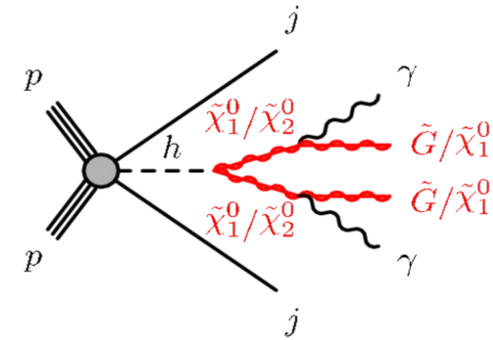
Higgs production through VBF considered

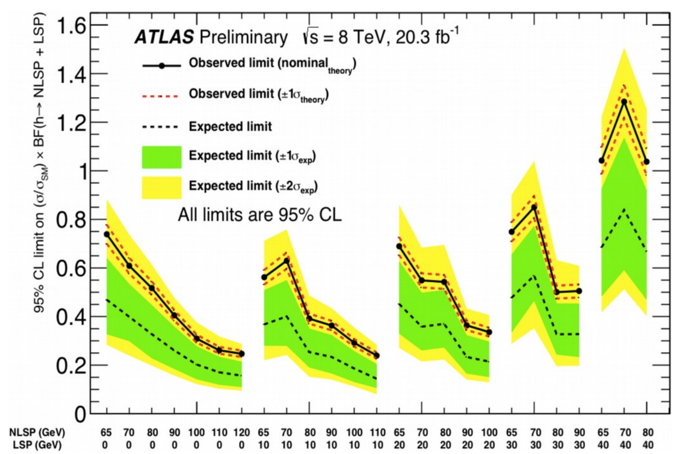
- **two additional jets**
- **widely separated**
- **High m_{jj}**

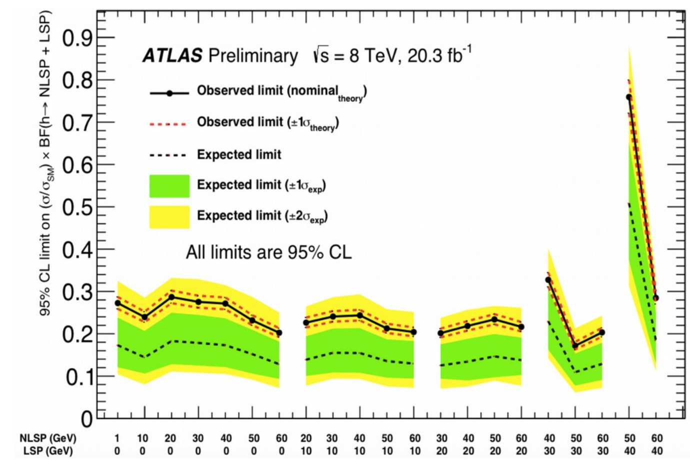
Main backgrounds

- **W/Z + jets**
  - Electron/jet/tau misidentification
- **Multijets and gamma + jets**









No excess above SM observed

- **Upper limits set on the cross-section x BR for these processes**

First ATLAS limits on the cross-section of such processes

Tau + jets + E_T^{miss} Analysis Overview

CERN-PH-EP-2014-144
CERN-PH-EP-2015-162

Four analysis channels

1) Exactly one tau — jet + E_T^{miss} trigger
2) At least two taus — jet + E_T^{miss} trigger
3) At least one tau and one electron — electron trigger
4) At least one tau and one muon — muon trigger

- **Additional selections:**
  - QCD rejection
  - SM rejection (H_T / m_{eff} / E_T^{miss})

All channels orthogonal to each other

- **Within each channel signal regions target specific signal types**
- **Statistical combination performed where relevant**

In the summary paper the analysis results combined with other SUSY analyses where applicable

- **The best performing analysis is picked for each signal point.**

Taus + jets + E_T^{miss} Background estimation

CERN-PH-EP-2014-144

CERN-PH-EP-2015-162

Main analysis backgrounds

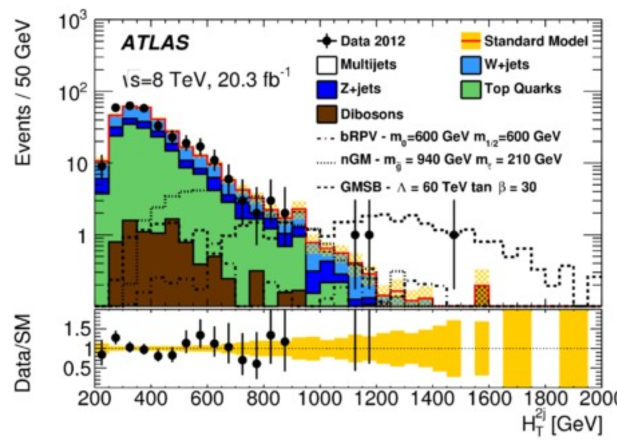
- **ttbar and single top**
- **W → τ ν + jets**
- **Z → τ τ + jets**
- **Z → ν ν + jets**
- **Multijets**

<u>Data-driven</u> estimation, others from simulation directly

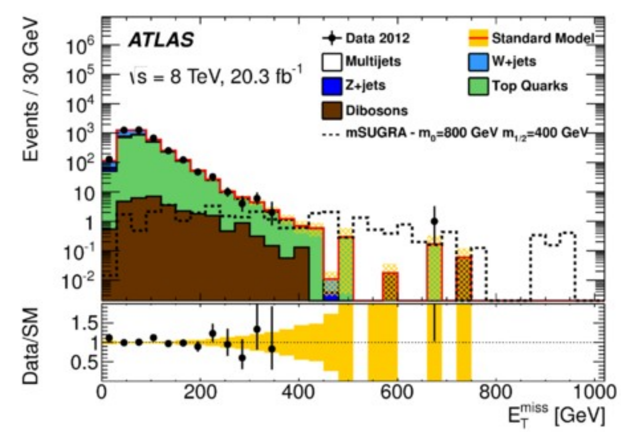
Example from one-tau analysis:

- **W/Z + jets and top estimated in control regions**
  - The number of events from each process estimated from data using matrix inversion
  - Scale factors to normalise distributions to data produced
- **Multijet background estimated from data using ABCD method**

2 tau



tau + mu



Results

CERN-PH-EP-2014-144
CERN-PH-EP-2015-162

	N_{obs}	N_{exp}^{SM}	S_{obs}^{95}	$\langle\epsilon\sigma\rangle_{obs}^{95}$ (fb)
1 tau loose	12	10.5 ± 1.4 ± 2.6	11.7	0.58
1 tau tight	3	2.4 ± 0.4 ± 0.8	5.9	0.29
2 tau inclusive	3	2.9 ± 0.4 ± 0.7	5.7	0.28
2 tau GMSB	0	0.28 ± 0.10 ± 0.22	3.4	0.17
2 tau nGM	1	3.1 ± 0.5 ± 0.9	3.8	0.18
2 tau bRPV	1	1.09 ± 0.19 ± 0.39	4.1	0.20
tau+e GMSB	1	1.34 ± 0.33 ± 0.80	4.1	0.20
tau+e nGM	8	4.3 ± 0.9 ± 2.0	11.4	0.56
tau+e bRPV	3	4.0 ± 0.8 ± 1.3	5.3	0.26
tau+e mSUGRA	14	10.0 ± 1.4 ± 3.0	14.6	0.72
tau+mu GMSB	2	0.98 ± 0.31 ± 0.35	5.3	0.26
tau+mu nGM	2	3.6 ± 0.9 ± 1.2	4.6	0.23
tau+mu bRPV	7	2.5 ± 0.6 ± 1.0	10.6	0.52
tau+mu mSUGRA	9	9.9 ± 1.5 ± 3.3	9.9	0.49

No excess observed above SM expectation in any signal region

Signal scenario	1τ SR	2τ SR	τ+lepton SR
GMSB	Tight	GMSB	GMSB
nGM	–	nGM	nGM
bRPV	Tight	bRPV	bRPV
mSUGRA	Tight	–	mSUGRA

Interpretations

nGM, bRPV-MSUGRA and mGMSB

CERN-PH-EP-2014-144

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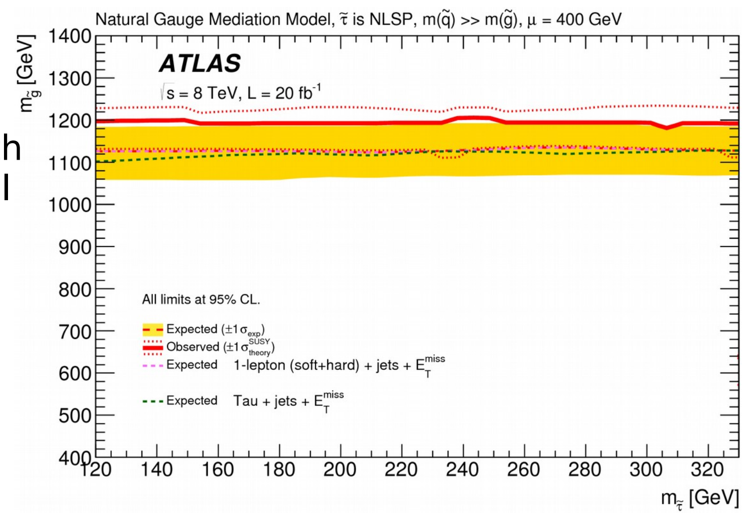
nGM

Combination with 1-lepton channel

m_g>1100 GeV

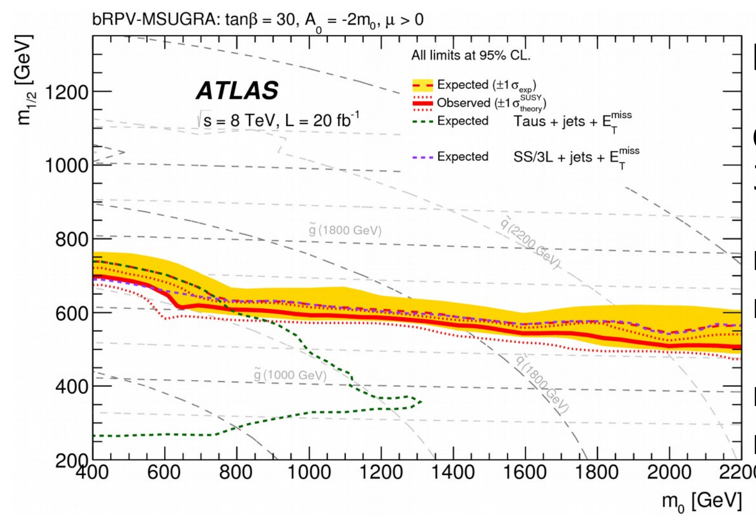


bRPV-mSUGRA

Combination with 3-lepton channel

m_0<750 GeV: $m_{1/2}$>680 GeV

m_0 >75 GeV: $m_{1/2}$>590GeV

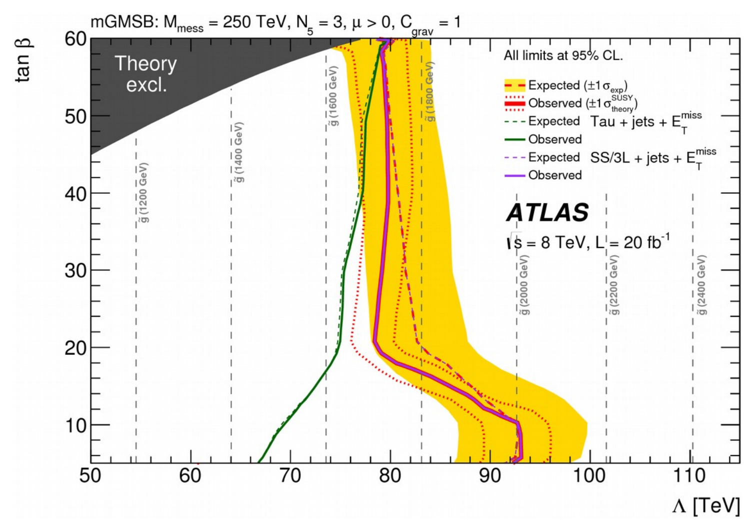


mGMSB

Combination with 3 letpton channel

Best exclusion 3 lepton channel

Λ > 75 TeV



Interpretation
Simplified two-step grids

CERN-PH-EP-2014-144
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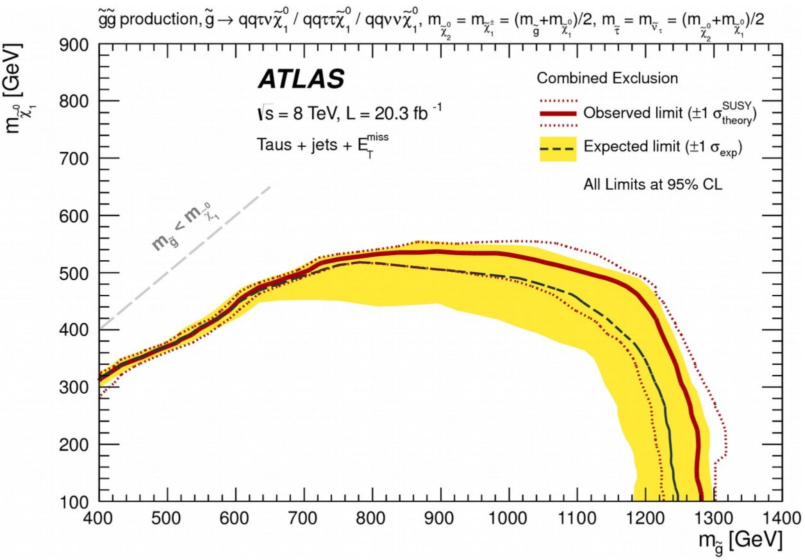
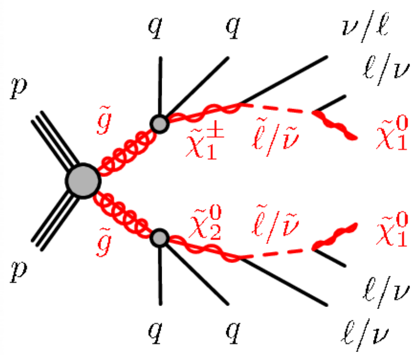
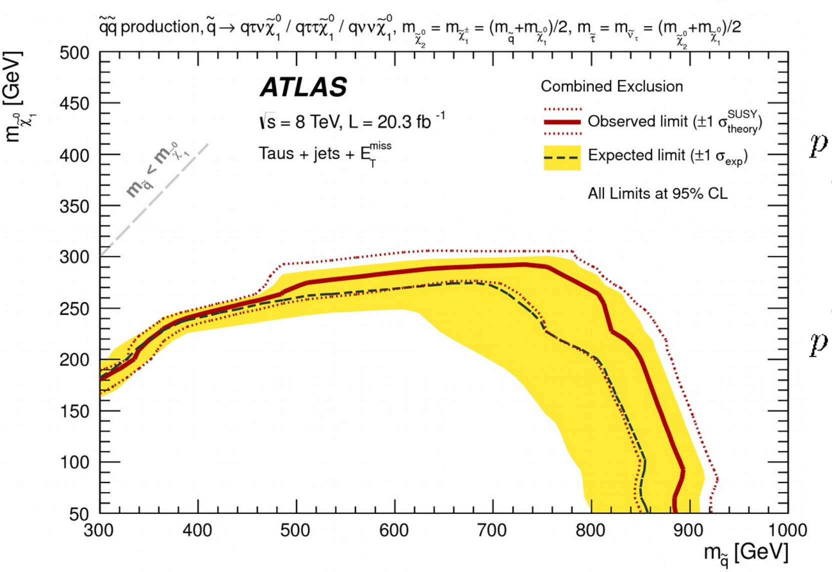
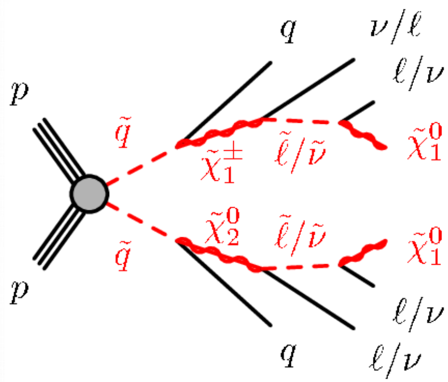




m_g > 1220 GeV
(light neutralino)

$m_{\tilde{\chi}}$ > 280 GeV
(light gluino)





m_q > 850 GeV
(light neutralino)

$m_{\tilde{\chi}}$ > 160 GeV
(light squark)

Conclusions

A large number of results for photon and tau signatures

- Many channels considered covering a wide range of final states
- No excesses above SM observed so far
- Limits set in a wide variety of models

Next round of searches for run-II already in progress!

Papers presented

I. "Search for photonic signatures of gauge-mediated supersymmetry in 8 TeV pp collisions with the ATLAS detector"
   CERN-PH-EP-2015-168 **arXiv**

II. "Search for exotic Higgs-boson decays in events with at least one photon, missing transverse momentum, and two forward jets produced in s = √8 TeV pp collisions with the ATLAS detector"
   ATLAS-CONF-2015-001 **CDS**

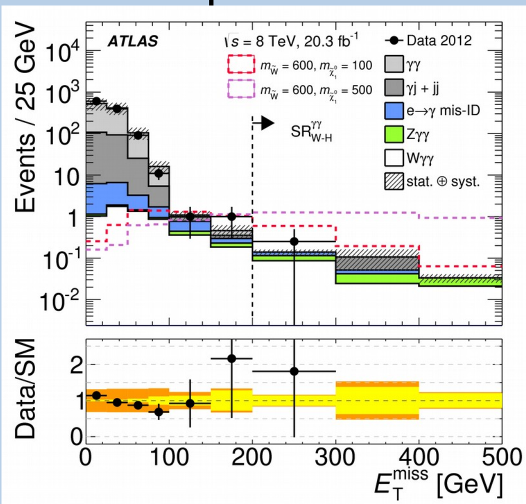
III. "Search for supersymmetry in events with large missing transverse momentum, jets, and at least one tau lepton in 20 fb^{-1} of s= √8 TeV proton-proton collision data with the ATLAS detector"
   CERN-PH-EP-2014-144 **arXiv**

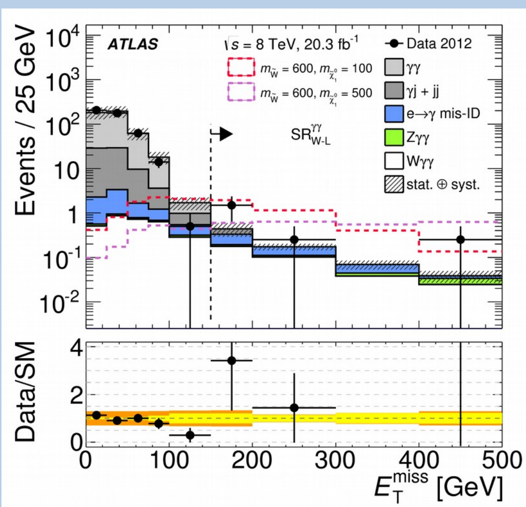
IV. "Search for supersymmetry in events with large missing transverse momentum, jets, and at least one tau lepton in 20 fb^{-1} of s√=8 TeV proton-proton collision data with the ATLAS detector"
   CERN-PH-EP-2015-162 **arXiv**

Back-up material

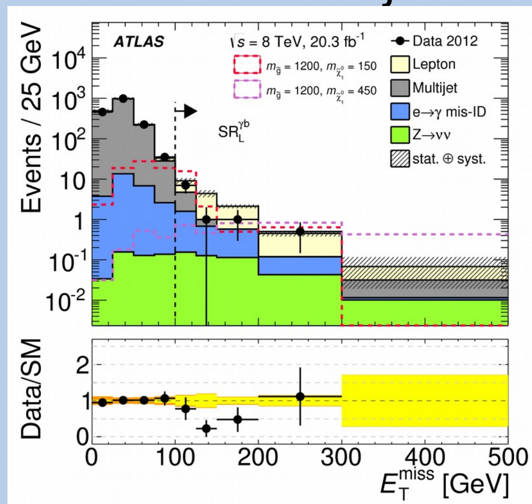
Photon analysis
Data/MC comparison

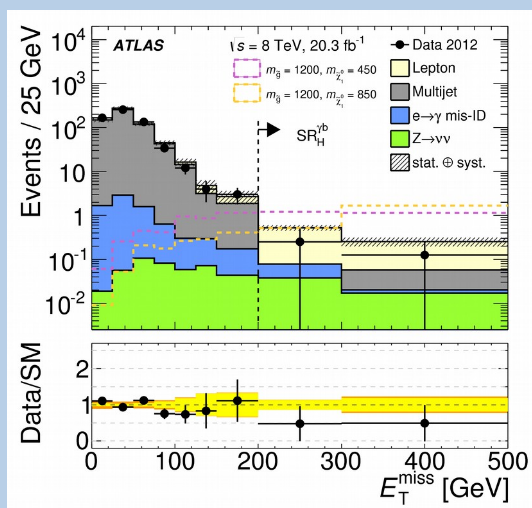
Diphoton



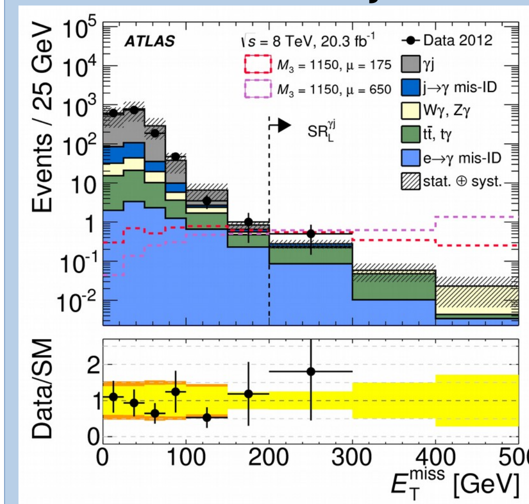


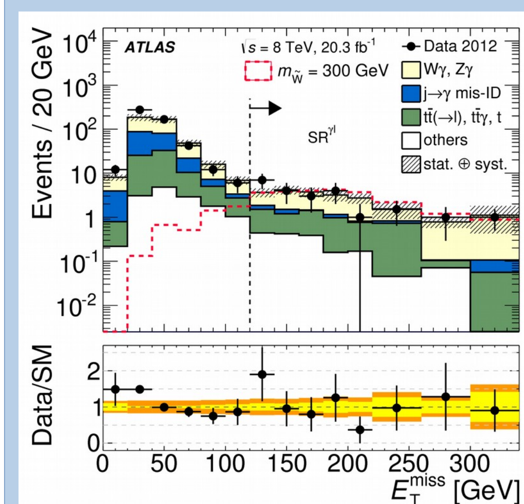
Photon + b-jet





Photon + jet





Tau + jets + E_T^{miss}
Background estimation methods

Background	1τ	2τ	τ+lepton
W+jets (true)	matrix inversion	matrix inversion	–
W+jets (fake)	matrix inversion		matrix inversion
Z+jets (true)	with W+jets	matrix inversion	–
Z+jets (fake)	with W+jets	–	–
Top (true)	matrix inversion	matrix inversion	matrix inversion
Top (fake)	matrix inversion		matrix inversion
Multijets	ABCD method	jet-smearing method	matrix method
Dibosons	from simulation	from simulation	from simulation

Background estimation methods used in each analysis channel

- **Generally split between true and fake tau contributions.**
- **These can be different as they arise from mismodelling in misidentified jets**