Searches for Gauge-Mediated Supersymmetry Breaking Signatures with the ATLAS Detector at the LHC

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ATLAS EXPERIMENT

Introduction

Status Quo

- $^2/_3$ through Run-2 of LHC, $93\,\mathrm{fb}^{-1}$ of luminosity at $\sqrt{s} = 13\,\mathrm{TeV}$ delivered in 2015 – 2017
- One year left before Long Shutdown 2, expect another $\sim 50\,\mathrm{fb}^{-1}$

This Talk

- **2 new ATLAS results** with interpretations in **gauge-mediated SUSY breaking** scenarios
  $\rightarrow 36.1\,\mathrm{fb}^{-1}$ (dataset from 2015 + 2016) $\leftarrow$
- Searches produced null results (observed yields consistent with SM expectations)

1. Photons + $E_{\mathrm{T}}^{\mathrm{miss}}$ *(ATLAS-CONF-2017-080)*
   "Search for photonic signatures of gauge-mediated supersymmetry in 13 TeV pp collisions with the ATLAS detector"
2. Higgsinos in $4b$: *(ATLAS-CONF-2017-081)*
   "Search for higgsino pair production in the hh topology in final states with ≥ 3 b-jets using the ATLAS detector in $\sqrt{s} = 13\,\mathrm{TeV}$ pp collisions"

Introduction

Gauge Mediated Supersymmetry Breaking — Motivation

- Natural models $\rightarrow$ expect light higgsinos, top squarks, (gluinos)
  - ATLAS & CMS: lower bounds on top squark and gluino masses up to TeV range in many models
  - higgsino states ($\widetilde{\chi}_1^0$, $\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^\pm$) often very close in mass, decays to $\widetilde{\chi}_1^0$ LSP yield soft particles escaping detection
    $\Rightarrow$ search experimentally challenging (light higgsinos = little $E_{\mathrm{T}}^{\mathrm{miss}}$)
- Gauge mediation: LSP = generally (very light) $\widetilde{G}$ instead of $\widetilde{\chi}_1^0$
  - NLSP $\rightarrow \widetilde{G}$ + bosons (Z^0, $W^\pm$, γ, h^0) $\Rightarrow E_{\mathrm{T}}^{\mathrm{miss}}$ + visible decay products
  - nature of NLSP relevant for phenomenology
    (here: admixture of gauginos and higgsinos)

Model Assumptions

- R-parity conservation
- all decays prompt
- $m(\widetilde{G})$ negligible

Interpretations of Search Results

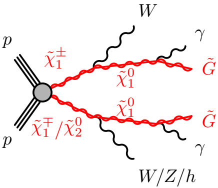
- Model-dependent limits using simplified models
  - limited particle content, only specific production mode(s) and decay chains
  - free parameters: masses and decay modes of relevant particles
- Model-independent upper limits on $\sigma_{\text{visible}}^{\text{BSM}} = \langle A\epsilon\sigma^{\text{BSM}}\rangle$

1.) Photons + $E_{\mathrm{T}}^{\mathrm{miss}}$
ATLAS-CONF-2017-080

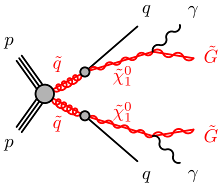
Photons + $E_{\mathrm{T}}^{\mathrm{miss}}$ — Overview

ATLAS-CONF-2017-080

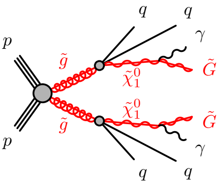
- Signature: energetic isolated photons and large $E_{\mathrm{T}}^{\mathrm{miss}}$
- Selections for two event classes: a) $\gamma\gamma$, b) γ + jets
- Four models for interpretation in GGM:
  - a) 3 models for $\gamma\gamma$: NLSP always bino-like; production of wino, squark or gluino pairs
  - b) 1 model for $\gamma +$ jets: NLSP = bino-higgsino admixture; production of gluino pairs
- General model assumptions:
  - a) for bino NLSP ($\gamma\gamma$): $\tilde{\chi}_1^0 \to \gamma\widetilde{G}$
  - b) for bino-higgsino NLSP ($\gamma +$ jets): BR$(\tilde{\chi}_1^0 \to \gamma\widetilde{G}) \sim 50\,\%$, BR$(\tilde{\chi}_1^0 \to Z\widetilde{G}) \sim 49\,\%$
- Model parameters: $m(\widetilde{W}/\tilde{q}/\tilde{g})$ and $m(\tilde{\chi}_1^0)$



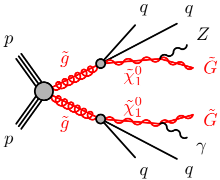
wino-bino model ($\gamma\gamma$)



squark-bino model ($\gamma\gamma$)

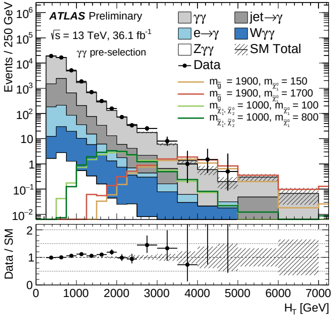


gluino-bino model ($\gamma\gamma$)



gluino-(higgsino-bino) model ($\gamma +$ jets)

- Trigger:
  - a) two photons (offline $p_{\mathrm{T}} > 75\,\mathrm{GeV}$)
  - b) one photon (offline $p_{\mathrm{T}} > 145\,\mathrm{GeV}$)
- a) 4 SRs for $\gamma\gamma$
  - 2 targeting $\tilde{g}$ and $\tilde{q}$ production
  - 2 for wino production
  - differ mostly by cuts on $E_{\mathrm{T}}^{\mathrm{miss}}$ (150 or 250 GeV) and H_{T} (1.0 – 2.75 TeV)
- b) 2 SRs for γ + jets
  - both with lepton veto
  - differ mostly by cuts on E_{T}^{γ} (145 or 400 GeV) and n_{jets} (≥ 5 or ≥ 3)



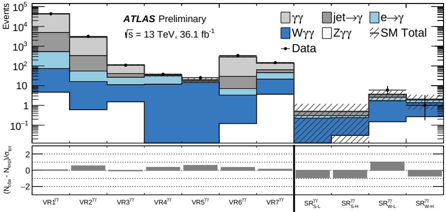
H_{T} ($= \sum_{\gamma,\ell,j} p_{\mathrm{T}}$) distribution in preselected $\gamma\gamma$ events

a) Backgrounds for $\gamma\gamma$

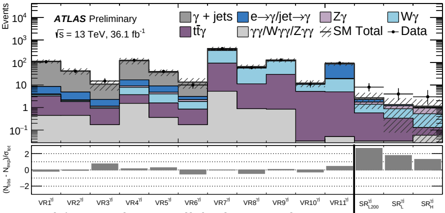
- QCD: some real $\gamma\gamma$, from MC$\times$SF,
  but mostly real γ + jet faking γ,
  from data CR$\times$SF for jet $\to \gamma$
- EWK: mostly real γ + e faking γ,
  from data CR$\times$SF for $e \to \gamma$
- irreducible background:
  $(W \to \ell\nu)\gamma\gamma$: MC normalized in CR,
  $(Z \to \nu\bar{\nu})\gamma\gamma$: MC

b) Backgrounds for γ + jets

- $W\gamma$, $t\bar{t}\gamma$, and γ + jets
  from MC normalized in CR
- $Z\gamma$, $\gamma\gamma/W\gamma\gamma/Z\gamma\gamma$ from MC
- $e \to \gamma$ / jet $\to \gamma$ as in a)



a) $\gamma\gamma$ validation regions | signal regions

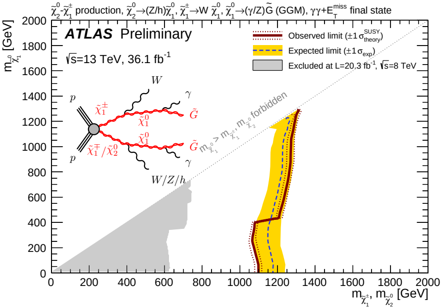


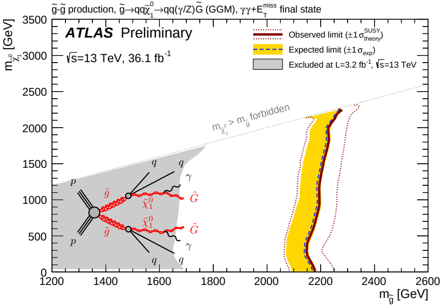
b) γ + jets validation regions | SRs

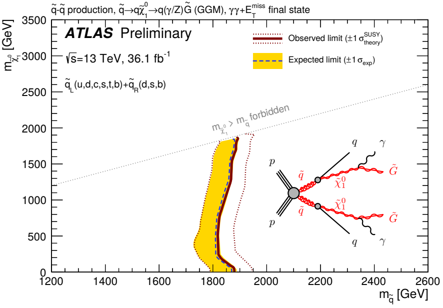
- Validation of background estimates in 7+11 VRs: good data-MC agreement

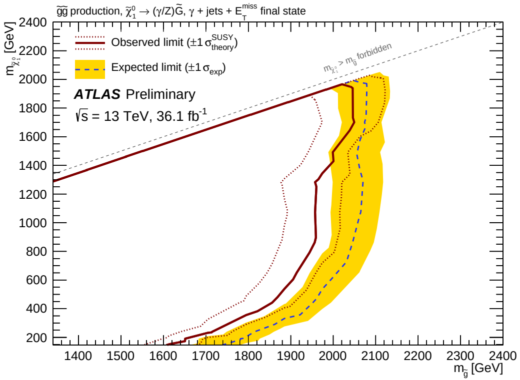
Photons + $E_{\mathrm{T}}^{\mathrm{miss}}$ — Interpretations: a) $\gamma\gamma$

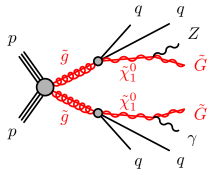
- No significant excess observed $\Rightarrow$ limits
- For each model point pick SR with best expected sensitivity
  - cross-over visible in wino-bino limit $\rightarrow$
- Wino-bino: $m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0) > 1070\,\mathrm{GeV}$
- $\tilde{g}$- / $\tilde{q}$-bino: $m(\tilde{g}/\tilde{q}) > 2140/1850\,\mathrm{GeV}$











gluino-(higgsino-bino) model
(γ + jets analysis)

- Observed lower limit on $m(\tilde{g})$: up to 2.05 TeV
- Limit: SR$_H^{\gamma j}$ better for small $\Delta m = m(\tilde{g}) - m(\tilde{\chi}_1^0)$, SR$_L^{\gamma j}$ for large Δm
  - 1.8σ excess in SR$_L^{\gamma j}$
  - ATLAS-CONF-2016-066 (ICHEP 2016, $13.3\,\text{fb}^{-1}$): 2.01σ in SR-L $\to$ now: 2.36σ

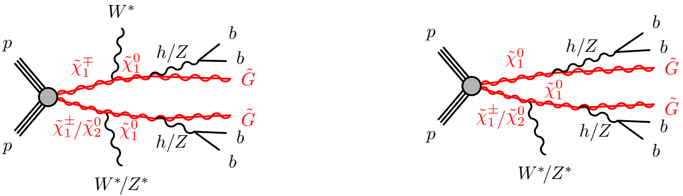
2.) Higgsinos in $4b$

ATLAS-CONF-2017-081

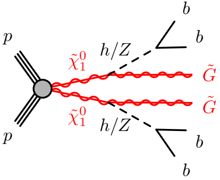
Higgsinos in $4b$

Overview

- Signature: 4 jets consistent with two $h \to b\bar{b}$ decays, plus $E_{\mathrm{T}}^{\mathrm{miss}}$
- Two complementary analyses, optimized for different $m(\tilde{\chi}_1^0)$
- Identify 2 Higgs candidates by pairing b-jets (and highest-p_{T} jets)



mass-degenerate higgsino triplet ($\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$) $\Rightarrow$ effective $\tilde{\chi}_1^0\tilde{\chi}_1^0$ production



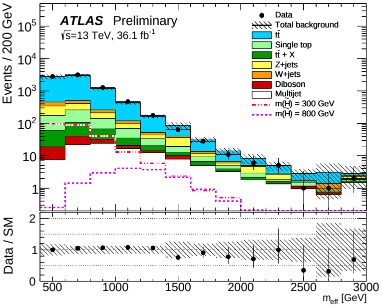
model parameters: higgsino mass and BR to h / Z

Selection (medium – high $m(\tilde{\chi}_1^0)$)

- $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
- 7 signal regions with ≥ 3 b-jets and $E_{\mathrm{T}}^{\mathrm{miss}} > 200\,\mathrm{GeV}$
  - mainly differ by $\max_{i=1,2} \Delta R(h_i)$ and $m_{\mathrm{eff}}^{4b\text{-jets}}$

Background Estimate

- background dominated by $t\bar{t}$ events ($\gtrsim 50\,\%$ in all SRs)
- simulation-based estimate + data-driven normalization for $t\bar{t}$ in CRs
- validated in sideband VRs



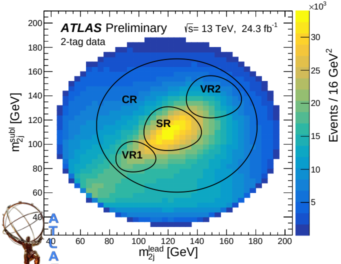
$m_{\mathrm{eff}}^{4b\text{-jets}}$
($E_{\mathrm{T}}^{\mathrm{miss}}$ + jets forming Higgs candidates)

Selection (low $m(\tilde{\chi}_1^0)$)

- b-jet triggers, lower luminosity ($24.3\,\mathrm{fb}^{-1}$)
- ≥ 4 b-jets with $p_\mathrm{T} > 40\,\mathrm{GeV}$
- Constraint on masses of Higgs candidates, 56 bins in $E_\mathrm{T}^\mathrm{miss}$ and $m_\mathrm{eff}^{4b\text{-jets}}$

Background Estimate

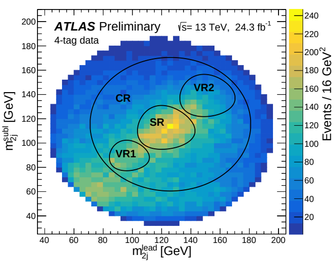
- overall background mostly multi-jet QCD events ($\sim 95\,\%$)
  - but 50 % leptonic $t\bar{t}$ events for $E_\mathrm{T}^\mathrm{miss} \gtrsim 200\,\mathrm{GeV}$
  - suppressed by rejecting events with lepton or compatible with top-quark decay
- fully data-driven background estimate (reweight data with 2 b- and ≥ 2 anti-b-tagged jets)



BDT reweighting $\longrightarrow$

correct for kinematic differences

(b-tagging efficiency, mistag rates, trigger effects, sample composition)

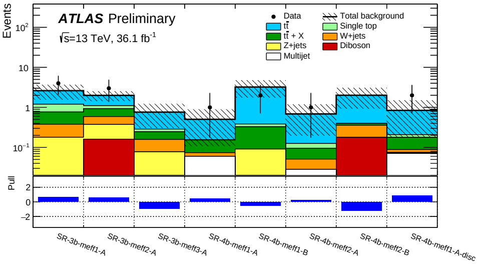


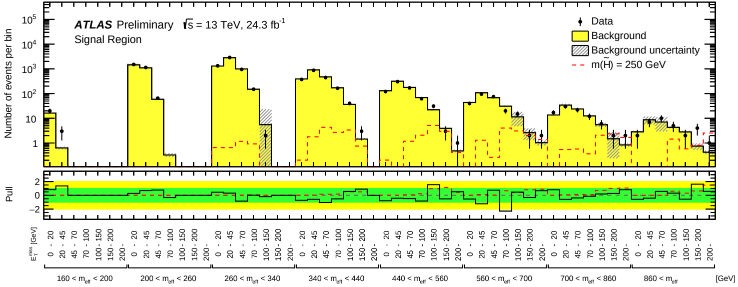
High-Mass Analysis

- Expected background and observed yields in SRs (and pulls) →
- No significant excess

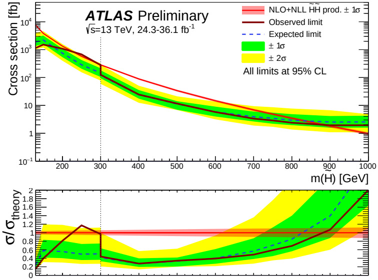
Low-Mass Analysis

- unrolled 56 bins of 2-D distribution of $E_{\mathrm{T}}^{\mathrm{miss}}$ and $m_{\mathrm{eff}}^{4b\text{-jets}}$ in the SR
- largest upward deviation: in penultimate bin (4 obs. vs. 1.0 ± 0.2 exp.) ↘

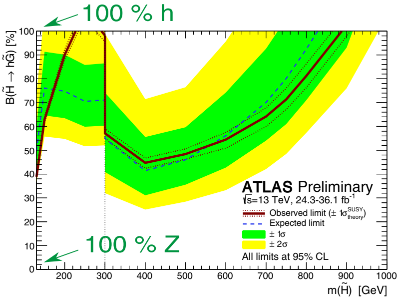




- No significant excess over expected SM background $\Rightarrow$ limits
- Regions of low- and high-mass analysis combined separately
- Pick analysis with best expected limit for each $m(\widetilde{\chi}_1^0)$ $\rightarrow$ transition at $300\,\mathrm{GeV}$



upper limits
on xsec of effective $\widetilde{\chi}_1^0\widetilde{\chi}_1^0$ production
(BR($\widetilde{\chi}_1^0 \rightarrow h\widetilde{G}$) = 100 %,
excluded $m(\widetilde{\chi}_1^0)$ range: 130 – 230, 290 – 880 GeV)



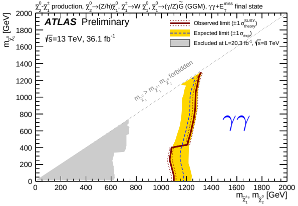
exclusion as function of BR($\widetilde{\chi}_1^0 \rightarrow h\widetilde{G}$) and $m(\widetilde{\chi}_1^0)$ for production with nominal xsec
(complementary analysis in prep.)

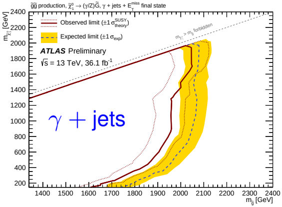
Summary & Outlook

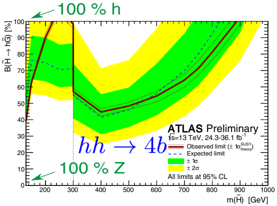
Halfway through Run-2

- Presented 2 new ATLAS analyses of $36.1\,\mathrm{fb}^{-1}$ pp collision data at $\sqrt{s} = 13\,\mathrm{TeV}$ with interpretations in SUSY scenarios that assume gauge-mediated SUSY breaking
- Motivation: "naturally light" higgsinos difficult to detect in gravity-mediated SB
- GMSB signatures: decays through higgs or electroweak gauge bosons to $\widetilde{G}$ LSP ($E_{\mathrm{T}}^{\mathrm{miss}}$)
- Some (mild) excesses to follow up — but no obvious signs for BSM physics

. . . already have the 2017 data to look at. . .







Web Page

- All public results of ATLAS SUSY searches on *(new design!)*: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Extra Material: Details of ATLAS Analyses

Signal Region	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$	$SR^{\gamma j}_{L}$	$SR^{\gamma j}_{L200}$	$SR^{\gamma j}_{H}$
Number of photons	≥ 2	≥ 2	≥ 2	≥ 2	≥ 1	≥ 1	≥ 1
E_{T}^{γ} [GeV]	> 75	> 75	> 75	> 75	> 145	> 145	> 400
Number of jets	...	...	...	...	≥ 5	≥ 5	≥ 3
Number of leptons	...	...	...	...	0	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 250	> 150	> 250	> 300	> 200	> 400
H_{T} [GeV]	> 2750	> 2000	> 1500	> 1000	...	...	...
m_{eff} [GeV]	...	...	...	...	> 2000	> 2000	> 2400
R_{T}^{4}	...	...	...	...	< 0.90	< 0.90	...
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.5	> 0.5	> 0.5	> 0.5	> 0.4	> 0.4	> 0.4
$\Delta\phi_{\mathrm{min}}(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$ ($\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$)	...	> 0.5	...	> 0.5	(> 0.4)	(> 0.4)	(> 0.4)

	$CR_{\gamma+\mathrm{jets}}$	$CR_{W\gamma}$	$CR_{t\bar{t}\gamma}$
N_{γ}	≥ 1	≥ 1	≥ 1
E_{T}^{γ}	> 145 GeV	> 145 GeV	> 145 GeV
N_{lep}	0	≥ 1	≥ 1
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 100 GeV	$[100 - 200]$ GeV	$[50 - 200]$ GeV
N_{jets}	≥ 3	≥ 1	≥ 2
$N_{b-\mathrm{jets}}$	...	0	≥ 2
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	< 0.4	> 0.4	> 0.4
$\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	...	...
m_{eff}	> 2000 GeV	> 500 GeV	> 500 GeV

	E_{T}^{γ} (GeV)	$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	N_{lep}	H_{T} (GeV)	$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	N_{exp}	N_{obs}
$VR1^{\gamma\gamma}$	> 75	> 0.5	...	...	< 150	43524 ± 4388	43918
$VR2^{\gamma\gamma}$	> 75	> 0.5	...	$(1000, 2500)$	< 150	2845 ± 522	3139
$VR3^{\gamma\gamma}$	> 75	> 0.5	...	...	$(100, 150)$	112 ± 36	109
$VR4^{\gamma\gamma}$	> 50	...	$1e$	< 2000	...	34.5 ± 7.2	38
$VR5^{\gamma\gamma}$	> 50	...	1μ	< 2000	...	19.8 ± 7.1	25
$VR6^{\gamma\gamma}$	> 75	> 0.5	...	> 1750	...	287 ± 129	336
$VR7^{\gamma\gamma}$	> 75	> 0.5	...	...	> 100	139 ± 40	146

	$VR1^{\gamma j}$	$VR2^{\gamma j}$	$VR3^{\gamma j}$	$VR4^{\gamma j}$	$VR5^{\gamma j}$	$VR6^{\gamma j}$
E_{T}^{γ} (GeV)	> 145	> 145	> 145	> 400	> 400	> 400
N_{lep}	0	0	0	0	0	0
N_{jets}	≥ 5	≥ 5	≥ 5	≥ 3	≥ 3	≥ 3
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4
$\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	$[50, 175]$	$[75, 175]$	$[100, 175]$	$[100, 175]$	$[125, 175]$	$[150, 175]$
m_{eff} (GeV)	> 2000	> 2000	> 2000	> 2000	> 2000	> 2000
R_{T}^{4}	< 0.90	< 0.90	< 0.90	...	...	...
N_{exp}	112 ± 20	42 ± 11	10.9 ± 4.1	120 ± 36	36.6 ± 9.9	13.4 ± 5.5
N_{obs}	108	41	15	126	40	10

	$VR7^{\gamma j}$	$VR8^{\gamma j}$	$VR9^{\gamma j}$	$VR10^{\gamma j}$	$VR11^{\gamma j}$
E_{T}^{γ} (GeV)	> 145	> 145	> 145	> 145	> 145
N_{lep}	≥ 1	≥ 1	≥ 1	≥ 1	...
N_{jets}	≥ 2	≥ 2	≥ 2	≥ 2	≥ 1
$N_{b-\mathrm{jets}}$	...	...	...	...	≥ 1
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	> 0.4	> 0.4	< 0.4	> 0.4
$\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	...	...	...	...	< 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	< 200	< 200	> 200	> 200	> 200
m_{eff} (GeV)	> 1000	> 1500	$[1000, 2000]$	> 1500	$[500, 2000]$
N_{exp}	408 ± 79	66 ± 12	127 ± 23	12.1 ± 2.1	87 ± 12
N_{obs}	410	59	129	11	94

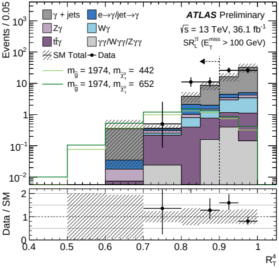
Signal Region	$\mathrm{SR}^{\gamma\gamma}_{S-L}$	$\mathrm{SR}^{\gamma\gamma}_{S-H}$	$\mathrm{SR}^{\gamma\gamma}_{W-L}$	$\mathrm{SR}^{\gamma\gamma}_{W-H}$
$\gamma\gamma$ (QCD)	$0.00^{+0.17}_{-0.00}$	$0.00^{+0.17}_{-0.00}$	$0.15^{+0.17}_{-0.15}$	$0.00^{+0.17}_{-0.00}$
jet $\to \gamma$	$0.19^{+0.21}_{-0.19}$	$0.19^{+0.21}_{-0.19}$	0.93 ± 0.67	$0.19^{+0.21}_{-0.19}$
e $\to \gamma$	0.08 ± 0.04	0.06 ± 0.04	0.88 ± 0.23	0.51 ± 0.15
$(W \to \ell\nu)\gamma\gamma$	0.22 ± 0.14	0.21 ± 0.13	1.55 ± 0.78	1.08 ± 0.56
$(Z \to \nu\nu)\gamma\gamma$	0.01 ± 0.01	0.03 ± 0.02	0.15 ± 0.08	0.27 ± 0.13
Expected background events	$0.50^{+0.30}_{-0.26}$	$0.48^{+0.30}_{-0.25}$	3.67 ± 1.07	$2.05^{+0.65}_{-0.63}$
Observed events	0	0	6	1

Signal Region	$\mathrm{SR}^{\gamma j}_{L}$	$\mathrm{SR}^{\gamma j}_{L200}$	$\mathrm{SR}^{\gamma j}_{H}$
γ + jets (QCD)	$0.00^{+0.21}_{-0.00}$	$0.42^{+0.43}_{-0.42}$	0.14 ± 0.14
$W\gamma$	0.54 ± 0.24	0.81 ± 0.22	0.40 ± 0.26
$Z\gamma$	0.31 ± 0.16	0.36 ± 0.13	0.42 ± 0.19
$t\bar{t}\gamma$	0.30 ± 0.11	0.54 ± 0.17	0.07 ± 0.03
$e \to \gamma$	0.07 ± 0.03	0.16 ± 0.06	0.04 ± 0.04
jet $\to \gamma$	$0.07^{+0.44}_{-0.07}$	$0.35^{+0.36}_{-0.35}$	$0.01^{+0.50}_{-0.01}$
$\gamma\gamma/W\gamma\gamma/Z\gamma\gamma$	0.03 ± 0.01	0.03 ± 0.01	0.06 ± 0.02
Expected background events	$1.33^{+0.58}_{-0.32}$	$2.68^{+0.64}_{-0.63}$	$1.14^{+0.61}_{-0.36}$
Observed events	4	8	3

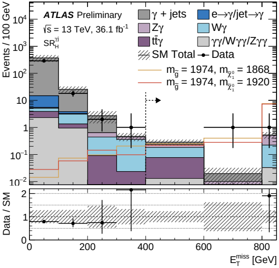
Signal Region	N_{obs}	$N^{\mathrm{SM}}_{\mathrm{exp}}$	S^{95}_{obs}	S^{95}_{exp}	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{exp}}$[fb]	Z (p)
$\mathrm{SR}^{\gamma\gamma}_{S-L}$	0	$0.50^{+0.30}_{-0.26}$	3.0	$3.2^{+1.4}_{-0.2}$	0.083	$0.089^{+0.039}_{-0.006}$	0.00 (0.50)
$\mathrm{SR}^{\gamma\gamma}_{S-H}$	0	$0.48^{+0.30}_{-0.25}$	3.0	$3.1^{+1.3}_{-0.1}$	0.083	$0.086^{+0.036}_{-0.003}$	0.00 (0.50)
$\mathrm{SR}^{\gamma\gamma}_{W-L}$	6	3.7 ± 1.1	8.3	$6.0^{+2.9}_{-1.6}$	0.230	$0.166^{+0.080}_{-0.044}$	0.87 (0.19)
$\mathrm{SR}^{\gamma\gamma}_{W-H}$	1	$2.05^{+0.65}_{-0.63}$	3.6	$4.7^{+1.8}_{-1.4}$	0.100	$0.130^{+0.050}_{-0.039}$	0.14 (0.45)
$\mathrm{SR}^{\gamma j}_{L}$	4	$1.33^{+0.54}_{-0.32}$	7.6	$4.7^{+1.6}_{-0.8}$	0.210	$0.130^{+0.044}_{-0.022}$	1.81 (0.035)
$\mathrm{SR}^{\gamma j}_{L200}$	8	$2.68^{+0.64}_{-0.63}$	11.5	$5.4^{+2.2}_{-1.2}$	0.318	$0.151^{+0.060}_{-0.033}$	2.36 (0.009)
$\mathrm{SR}^{\gamma j}_{H}$	3	$1.14^{+0.61}_{-0.36}$	6.6	$5.9^{+1.8}_{-1.1}$	0.183	$0.162^{+0.050}_{-0.030}$	1.20 (0.116)

- additional $\mathrm{SR}^{\gamma j}_{L200}$, to follow-up on excess in $13.2\,\mathrm{fb}^{-1}$
    - exp. 0.78 ± 0.18, obs. 3 $\Rightarrow Z = 2.01$
- same as $\mathrm{SR}^{\gamma j}_{L}$ but lower $E_{\mathrm{T}}^{\mathrm{miss}}$ cut

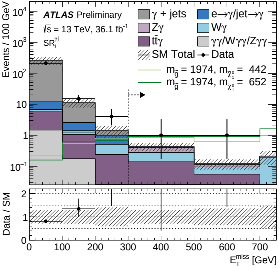
Photons + $E_{\mathrm{T}}^{\mathrm{miss}}$ — SR Plots



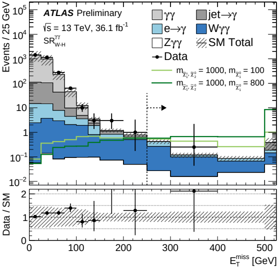
R_T^4 in SR$_L^{\gamma j}$ with relaxed $E_{\mathrm{T}}^{\mathrm{miss}}$ cut



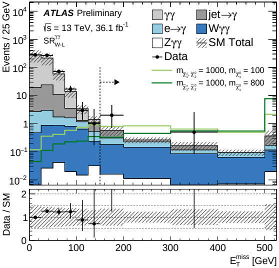
$E_{\mathrm{T}}^{\mathrm{miss}}$ in SR$_H^{\gamma j}$



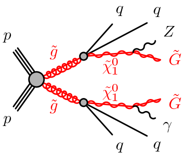
$E_{\mathrm{T}}^{\mathrm{miss}}$ in SR$_L^{\gamma j}$

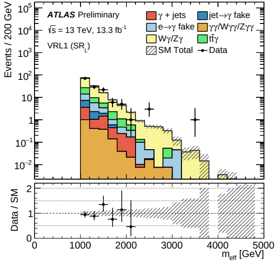


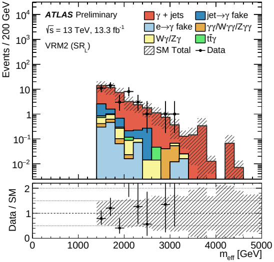
$E_{\mathrm{T}}^{\mathrm{miss}}$ in SR$_{W-H}^{\gamma\gamma}$



$E_{\mathrm{T}}^{\mathrm{miss}}$ in SR$_{W-L}^{\gamma\gamma}$



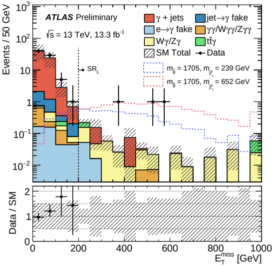




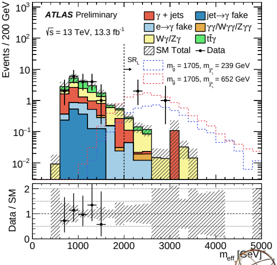
	$\mathrm{SR_L}$	$\mathrm{SR_H}$
N_{photons}	> 0	> 0
$p_{\mathrm{T}}^{\mathrm{leading}-\gamma}$	> 145 GeV	> 400 GeV
N_{leptons}	0	0
N_{jets}	> 4	> 2
$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	> 0.4
$\Delta\phi(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 200 GeV	> 400 GeV
m_{eff}	> 2000 GeV	> 2000 GeV
R_{T}^4	< 0.90	-

$$R_T^4 = \frac{\sum_{i=1}^{4} p_{\mathrm{T}}^i}{\sum_{\mathrm{jets}} p_{\mathrm{T}}^j}$$

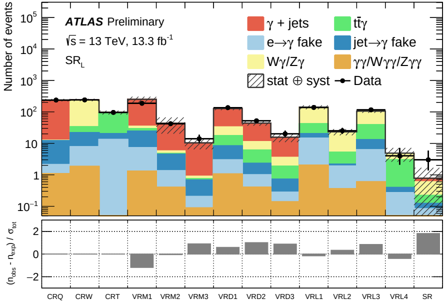
2 VRs defined with same selection as for SRs but for lower $E_{\mathrm{T}}^{\mathrm{miss}}$ and looser m_{eff} requirements



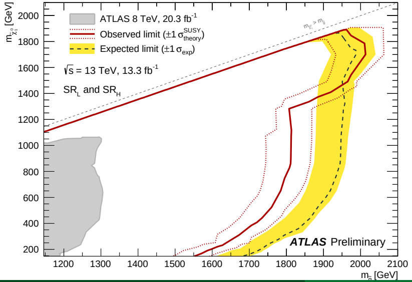
$E_{\mathrm{T}}^{\mathrm{miss}}$ in SR_L



m_{eff} in SR_L



Signal Region	SR_L	SR_H
Observed events	3	1
Expected SM events	0.78 ± 0.18	1.49 ± 0.45
γ + jets	0.18 ± 0.11	0.70 ± 0.24
$W\gamma$	0.30 ± 0.07	0.37 ± 0.09
$Z\gamma$	0.08 ± 0.08	0.32 ± 0.32
$t\bar{t}\gamma$	0.10 ± 0.04	0.03 ± 0.01
$e \to \gamma$ fakes	0.07 ± 0.03	0.00 ± 0.00
jet $\to \gamma$ fakes	0.04 ± 0.01	0.00 ± 0.00
$\gamma\gamma/W\gamma\gamma/Z\gamma\gamma$	0.01 ± 0.00	0.07 ± 0.01



	Real E_T^{miss}	Instrumental E_T^{miss}
Real photon	$Z(\to \nu\nu)\gamma$, $Z\gamma\gamma$, $W\gamma$, $W\gamma\gamma$, $t\bar{t}\gamma$	γ+jets, $\gamma\gamma$
e/jet fakes	W+jets, $Z(\to \nu\nu)$+jets, $t\bar{t}$, dibosons	Multijet, $Z(\to ll)$+jets

	$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$ (Z)
SR_L	0.48	6.4	$3.7^{+1.2}_{-0.2}$	0.97	0.02 (2.01)
SR_H	0.28	3.7	$4.4^{+0.9}_{-0.9}$	0.34	0.65 (−0.39)

Jet Pairing

- high-mass analysis
  - choose jets: $= 4$ b-jets (with highest p_T) or 3 b-jets and highest-p_T jet
  - best signal efficiency: minimize $\Delta R^{b,b}_{\mathrm{max}} = \max(\Delta R(h_1), \Delta R(h_2))$, $\Delta R(h)$: distance in y–ϕ space between jets forming Higgs candidate
- low-mass analysis
  - choose 4 jets with highest b-tagging scores
  - minimize $D_{hh} = \left| m^{\mathrm{lead}}_{2j} - \frac{120}{110} m^{\mathrm{sublead}}_{2j} \right|$ in plane of Higgs boson candidate masses, "leading" = Higgs boson candidate with largest scalar sum p_T of the jet constituents
  - numeric values = medians of narrowest intervals in m^{lead}_{2j} and $m^{\mathrm{sublead}}_{2j}$ containing 90 % of signal
- D_{hh} also tried in high-mass
  - but sub-optimal because high mass $\Rightarrow$ Higgs bosons larger p_T $\Rightarrow$ smaller ΔR separation of b-jets $\Rightarrow \Delta R^{b,b}_{\mathrm{max}}$ highly efficient
- $\Delta R^{b,b}_{\mathrm{max}}$ also tried in low-mass
  - but sub-optimal because low mass $\Rightarrow$ Higgs bosons lower p_T $\Rightarrow$ larger ΔR separation (of b-jets) $\Rightarrow$ wrong pairings more often than with D_{hh}

Higgsinos in $4b$ — Details on Region Definitions

	SR-3b-meff1-A	SR-3b-meff2-A	SR-3b-meff3-A	SR-4b-meff1-A	SR-4b-meff1-B	SR-4b-meff2-A	SR-4b-meff2-B	SR-4b-meff1-A-disc
$N_{\text{b-jet}}$	=3	=3	≥3	≥4	≥4	≥4	≥4	≥ 4
E_T^{miss}	> 200							
$\Delta\phi_{\text{min}}^{4j}$	>0.4							
N_{jet}	4-5	4-5	4-5	4-5	4-5	4-6	4-6	4-5
$m_{T,\text{min}}^{b-\text{jets}}$	>150	>150	>130	-	-	-	-	-
m(h1)	110-150							
m(h2)	90-140							
$\Delta R_{\text{max}}^{bb}$	0.4-1.4	0.4-1.4	0.4-1.4	0.4-1.4	1.4-2.4	0.4-1.4	1.4-2.4	0.4-1.4
m_{eff}	600-850	850-1100	>1100	600-850	600-850	850-1100	850-1100	> 600

SR definitions for high-mass analysis

Region	Lower threshold [GeV] E_T^{miss}	m_{eff}
low-SR-MET0-meff440	0	440
low-SR-MET150-meff440	150	440

discovery regions for low-mass analysis

	CR-3b-meff1	CR-3b-meff2	CR-3b-meff3	CR-4b-meff1	CR-4b-meff2
$N_{\text{b-jet}}$	=3	=3	≥3	≥4	≥4
E_T^{miss}	> 200				
$\Delta\phi_{\text{min}}^{4j}$	>0.4				
N_{jet}	4-5	4-5	4-5	4-5	4-6
$m_{T,\text{min}}^{b-\text{jets}}$	>100	>100	>100	-	-
m(h1), m(h2)	(m(h1)<80, m(h2)<80) or (m(h1)>150, m(h2)<80) or (m(h1)>150, m(h2)>140)				
$\Delta R_{\text{max}}^{bb}$	0.4-4	0.4-4	0.4-4	0.4-4	≥ 0.4
m_{eff}	600-850	850-1100	>1100	600-850	850-1100

CR definitions high-mass analysis

	VR-3b-meff1-A	VR-3b-meff2-A	VR-3b-meff3-A	VR-4b-meff1-A	VR-4b-meff1-B	VR-4b-meff2-A	VR-4b-meff2-B
$N_{\text{b-jet}}$	=3	=3	≥3	≥4	≥4	≥4	≥4
E_T^{miss}	>200						
$\Delta\phi_{\text{min}}^{4j}$	>0.4						
N_{jet}	4-5	4-5	4-5	4-5	4-5	4-6	4-6
$m_{T,\text{min}}^{b-\text{jets}}$	>120	>100	>80	-	-	-	-
m(h1), m(h2)	(80<m(h1)<150, m(h2)<80) or (m(h1)>150, 90<m(h2)<140)						
$\Delta R_{\text{max}}^{bb}$	0.4-1.5	0.4-1.7	0.4-1.7	0.4-1.7	1.4-3	0.4-1.7	1.4-3
$m_{\text{eff}}^{4b-\text{jets}}$	550-900	800-1150	>1050	550-900	550-900	800-1150	800-1150

VR def's high-mass (CRs/VRs differ by $m(h_{1,2})$)

- Signal selection in low-mass analysis:
  - veto $X_{Wt} < 1.8$ (against leptonic $t\bar{t}$)
  - require $X_{hh}^{SR} < 1.6$
  - 7 bins in E_T^{miss} (starting at 0 GeV) $\times$
    8 bins in $m_{\text{eff}}^{4b\text{-jets}}$ (starting at 160 GeV)

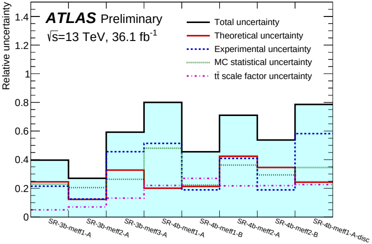
$$X_{Wt} = \sqrt{\left(\frac{m_W - 80.4\ \text{GeV}}{0.1 m_W}\right)^2 + \left(\frac{m_t - 172.5\ \text{GeV}}{0.1 m_t}\right)^2}$$

$$X_{hh}^{\text{SR}} = \sqrt{\left(\frac{m_{2j}^{\text{lead}} - 120\ \text{GeV}}{0.1 \times m_{2j}^{\text{lead}}}\right)^2 + \left(\frac{m_{2j}^{\text{subl}} - 110\ \text{GeV}}{0.1 \times m_{2j}^{\text{subl}}}\right)^2}$$

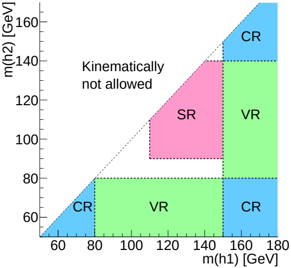
$$R_{hh}^{\text{CR}} \equiv \sqrt{(m_{2j}^{\text{lead}} - 126.0\ \text{GeV})^2 + (m_{2j}^{\text{subl}} - 115.5\ \text{GeV})^2},$$

$$X_{hh}^{\text{VR1}} \equiv \sqrt{\left(\frac{m_{2j}^{\text{lead}} - 96\ \text{GeV}}{0.1 \times m_{2j}^{\text{lead}}}\right)^2 + \left(\frac{m_{2j}^{\text{subl}} - 88\ \text{GeV}}{0.1 \times m_{2j}^{\text{subl}}}\right)^2},$$

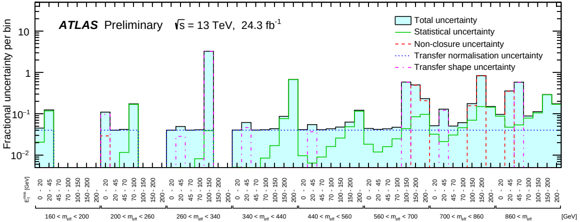
$$X_{hh}^{\text{VR2}} \equiv \sqrt{\left(\frac{m_{2j}^{\text{lead}} - 149\ \text{GeV}}{0.1 \times m_{2j}^{\text{lead}}}\right)^2 + \left(\frac{m_{2j}^{\text{subl}} - 137\ \text{GeV}}{0.1 \times m_{2j}^{\text{subl}}}\right)^2}.$$



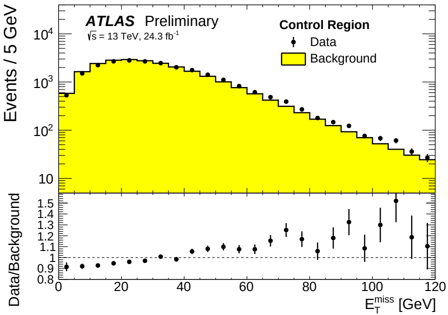
Systematic uncertainties (high-mass)



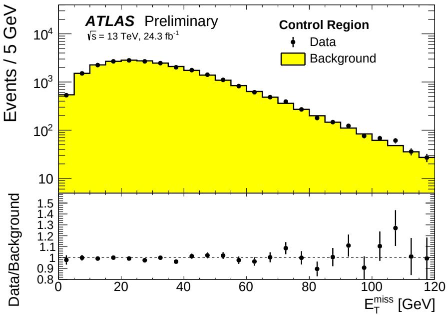
High-mass analyis setup



Systematic uncertainties (low-mass)



$E_{\mathrm{T}}^{\mathrm{miss}}$ in CR before...

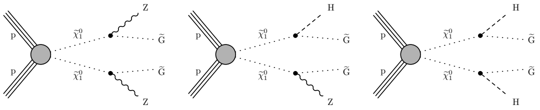


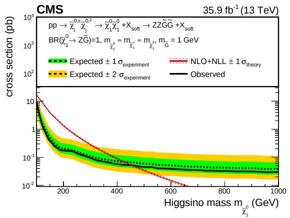
...and after BDT reweighting

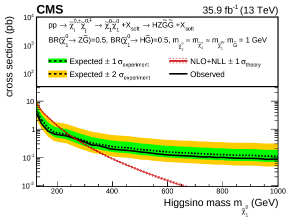
model-independent limits $\rightarrow$

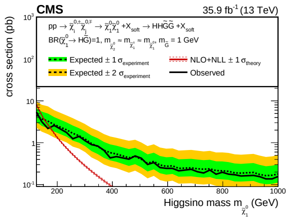
Signal channel	N_{obs}	N_{pred}	$\langle A\epsilon\sigma\rangle_{obs}^{95}$[fb]	S_{obs}^{95}	S_{exp}^{95}	CL_B	$p(s=0)$
high-SR-4b-meff1-A-disc	2	0.8 ± 0.7	0.15	5.5	$4.2^{+1.3}_{-0.4}$	0.84	0.15 (1.02)
high-SR-3b-meff3-A	0	0.8 ± 0.5	0.08	3.1	$3.1^{+1.2}_{-0.1}$	0.61	0.71 (−0.55)
low-SR-MET0-meff440	1063	1100 ± 25	2.3	56.1	$78.8^{+31.3}_{-22.8}$	0.16	0.80 (−0.84)
low-SR-MET150-meff440	17	11.5 ± 8.2	0.90	21.8	$19.0^{+4.9}_{-4.0}$	0.76	0.21 (0.80)

Extra Material: CMS Counterparts

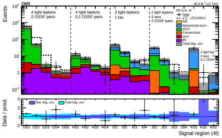






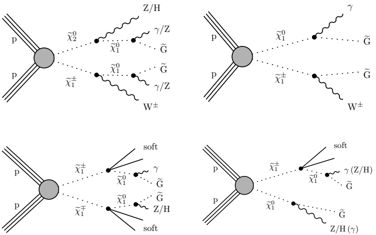


Model	Categories used
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, flavor-democratic, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.5\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	A
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, flavor-democratic, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.05\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	SS, A
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, flavor-democratic, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.95\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	SS, A
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, τ-enriched, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.05\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	A, C
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, τ-enriched, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.5\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	A, C
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, τ-enriched, $m_{\tilde\ell} = m_{\tilde\chi_1^0} + 0.95\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	A, C
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, τ-dominated, $m_{\tilde\tau} = m_{\tilde\chi_1^0} + 0.5\cdot(m_{\tilde\chi_2^0} - m_{\tilde\chi_1^0})$	B–F
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, heavy sleptons, $\tilde\chi_1^\pm\tilde\chi_2^0 \to WZ$	A
$\tilde\chi_1^\pm\tilde\chi_2^0$ production, heavy sleptons, $\tilde\chi_1^\pm\tilde\chi_2^0 \to WH$	SS, A–K
$\tilde\chi_1^0\tilde\chi_1^0$ production, $\tilde\chi_1^0\tilde\chi_1^0 \to ZZ\tilde G\tilde G$	A–K
$\tilde\chi_1^0\tilde\chi_1^0$ production, $\tilde\chi_1^0\tilde\chi_1^0 \to HZ\tilde G\tilde G$	A–K
$\tilde\chi_1^0\tilde\chi_1^0$ production, $\tilde\chi_1^0\tilde\chi_1^0 \to HH\tilde G\tilde G$	A–K

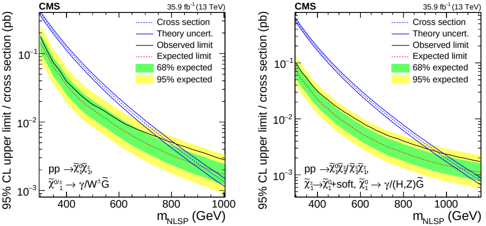


p_T^{miss} (GeV)	$0\tau_h$				$1\tau_h$		$2\tau_h$			
	nOSSF ≥ 2		nOSSF < 2		nOSSF ≥ 0		nOSSF ≥ 2		nOSSF < 2	
	G		H		I		J		K	
	(exp.)	(obs.)	(exp.)	(obs.)	(exp.)	(obs.)	(exp.)	(obs.)	(exp.)	(obs.)
0 – 50	460 ± 120	619	10.9 ± 2.2	14	42 ± 8	51	30 ± 7	29	24 ± 8	30
50 – 100	45 ± 14	51	7.7 ± 1.5	6	16.4 ± 3.5	14	5.7 ± 1.7	5	$0.07^{+0.18}_{-0.07}$	1
100 – 150	2.7 ± 0.8	2	2.7 ± 0.6	0	4.7 ± 1.4	4	0.9 ± 0.5	1	0.6 ± 0.4	0
150 – 200	1.12 ± 0.33	2	1.9 ± 0.6	1	2.9 ± 0.9	5	0.63 ± 0.32	0		
≥200	0.97 ± 0.32	0								

(only 4ℓ event categories G – K above, ∃ many more in 3ℓ = A – F)

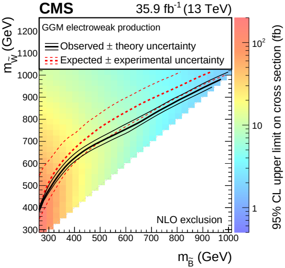


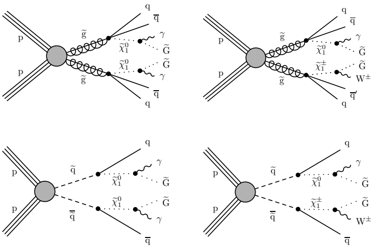
top left: GGM, top right: "TChiWg", bottom: "TChiNg"



"TChiWg" (left) and "TChiNg" (right)

Region	Selection
Preselection	p_T^{miss} filters At least one reconstructed vertex At least one photon with $p_T > 180\,\mathrm{GeV}$ $\Delta R(\gamma,\mathrm{jet}) > 0.5$ $\Delta\phi(\vec{p}_T^{miss},\mathrm{jet}) > 0.3\,\mathrm{rad}$, if $p_T(\mathrm{jet}) > 100\,\mathrm{GeV}$
Control region	Preselection $p_T^{miss} > 100\,\mathrm{GeV}$ $M_T(\gamma,\vec{p}_T^{miss}) > 100\,\mathrm{GeV}$ $p_T^{miss} < 300\,\mathrm{GeV}$ or $M_T(\gamma,\vec{p}_T^{miss}) < 300\,\mathrm{GeV}$
Validation region	Preselection $p_T^{miss} > 300\,\mathrm{GeV}$ $M_T(\gamma,\vec{p}_T^{miss}) > 300\,\mathrm{GeV}$ $S_T^{\gamma} < 600\,\mathrm{GeV}$
Signal region	Preselection $p_T^{miss} > 300\,\mathrm{GeV}$ $M_T(\gamma,\vec{p}_T^{miss}) > 300\,\mathrm{GeV}$ $S_T^{\gamma} > 600\,\mathrm{GeV}$





S_{T}^{γ}: 600–800 GeV

	Yield	σ_{stat}	σ_{syst}
$V(\gamma)$	213	4.4	21.3
γ+jets	5	1.1	0.5
$t\bar{t}(\gamma)$	13	5.7	3.9
$e \to \gamma$	29	0.9	14.2
Diboson	7	2.8	2.1
Total	267	7.9	26.0
Data	281		

S_{T}^{γ}: 800–1000 GeV

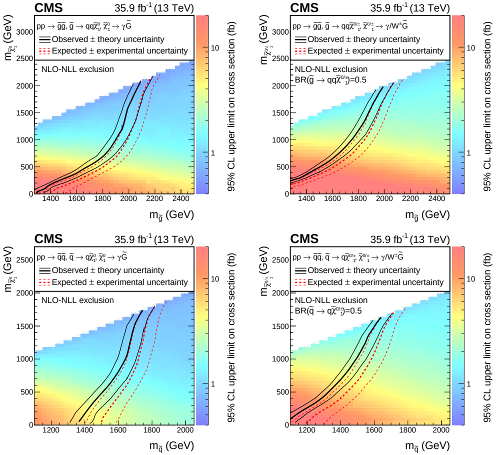
	Yield	σ_{stat}	σ_{syst}
$V(\gamma)$	76.8	1.9	8.1
γ+jets	4.4	1.2	0.4
$t\bar{t}(\gamma)$	8.0	3.8	2.4
$e \to \gamma$	9.2	0.5	4.6
Diboson	1.9	1.7	0.6
Total	100.2	4.7	9.7
Data	101		

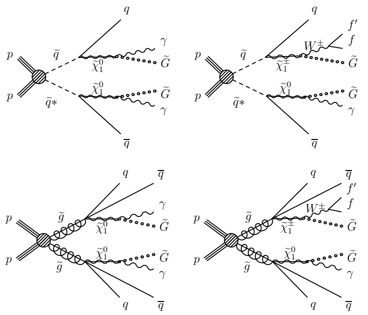
S_{T}^{γ}: 1000–1300 GeV

	Yield	σ_{stat}	σ_{syst}
$V(\gamma)$	35.0	1.3	3.9
γ+jets	4.2	1.3	0.4
$t\bar{t}(\gamma)$	3.5	0.9	1.1
$e \to \gamma$	4.7	0.4	2.3
Diboson	5.4	3.0	1.6
Total	52.8	3.6	5.0
Data	65		

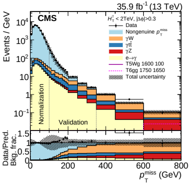
S_{T}^{γ}: >1300 GeV

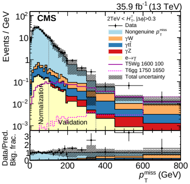
	Yield	σ_{stat}	σ_{syst}
$V(\gamma)$	12.6	0.7	1.6
γ+jets	1.1	0.5	0.4
$t\bar{t}(\gamma)$	0.7	0.5	0.2
$e \to \gamma$	1.5	0.2	0.8
Diboson	1.7	1.7	0.5
Total	17.6	2.0	1.9
Data	24		

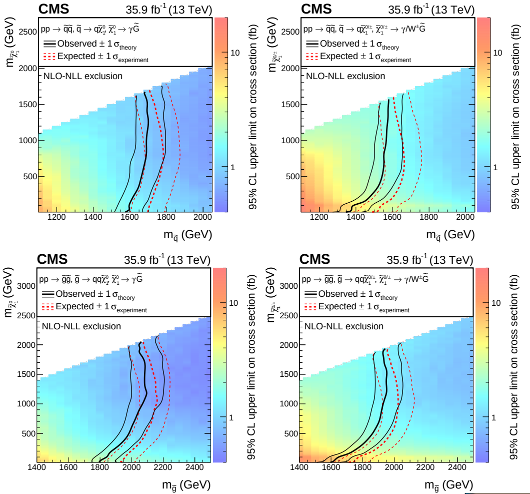




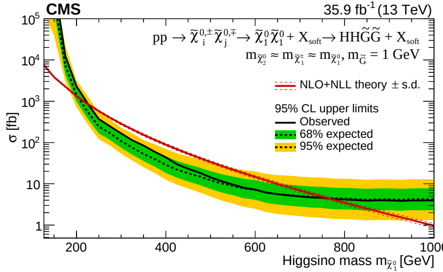
H_T^γ (GeV)	<2000			>2000		
p_T^{miss} (GeV)	(350, 450)	(450, 600)	>600	(350, 450)	(450, 600)	>600
Nongenuine p_T^{miss}	$9.6^{+11.1}_{-9.6}$	$2.2^{+5.5}_{-2.2}$	< 0.1	2.83 ± 2.51	1.31 ± 0.74	$0.73^{+0.86}_{-0.73}$
γW	51.3 ± 9.7	29.1 ± 5.5	11.6 ± 2.5	1.58 ± 0.58	0.70 ± 0.37	1.23 ± 0.43
$\gamma t\bar{t}$	17.1 ± 5.4	5.6 ± 2.6	1.9 ± 0.4	0.97 ± 0.38	0.45 ± 0.29	0.40 ± 0.22
γZ	11.5 ± 2.4	9.7 ± 1.8	7.1 ± 1.4	0.12 ± 0.07	0.25 ± 0.11	0.21 ± 0.10
$e \to \gamma$	15.1 ± 4.6	6.3 ± 1.9	1.4 ± 0.5	0.21 ± 0.10	0.13 ± 0.07	0.05 ± 0.04
Total bkg.	104.6 ± 16.5	53.0 ± 8.6	22.0 ± 3.0	5.72 ± 2.60	2.84 ± 0.89	2.62 ± 0.99
Data	103	82	21	6	10	4
T5Wg 1600 100	0.4 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	3.66 ± 0.40	3.09 ± 0.40	2.41 ± 0.32
T6gg 1750 1650	0.5 ± 0.1	0.8 ± 0.1	4.9 ± 0.4	0.31 ± 0.04	0.46 ± 0.07	4.12 ± 0.32







$\mathcal{L} = 35.9\,\mathrm{fb}^{-1}$	Other	Single t	QCD	V+jets	$t\bar{t}+X$	Total SM bkg.	TChiHH (225,1)	TChiHH (400,1)	TChiHH (700,1)
No selection	—	—	—	—	—	—	10477.0	1080.3	84.0
0ℓ, 4–5 jets	—	—	—	—	—	—	4442.0	544.9	44.6
$N_{b,T} \geq 2$	—	—	—	—	—	—	2509.3	308.9	23.9
$p_T^{miss} > 150\,\mathrm{GeV}$	122.3	1847.0	13201.4	2375.8	26797.7	44344.2 ± 778.5	509.5	204.2	20.4
Track veto	91.4	1130.1	12251.8	1987.0	16910.1	32370.5 ± 770.5	476.9	196.3	19.9
$\Delta\phi_{1,2} > 0.5, \Delta\phi_{3,4} > 0.3$	62.3	688.4	1649.0	1466.6	12027.0	15893.4 ± 482.6	267.2	162.3	17.5
$\lvert\Delta m\rvert < 40\,\mathrm{GeV}$	35.9	366.0	831.9	745.5	7682.3	9661.6 ± 440.8	191.8	119.4	12.2
$\Delta R_{max} < 2.2$	14.2	138.2	147.0	336.9	3014.2	3650.5 ± 90.2	98.3	79.6	10.1
$100 < \langle m \rangle \leq 140\,\mathrm{GeV}$	3.8	42.3	14.0	75.2	992.0	1127.3 ± 10.1	72.9	61.0	8.3
3b + 4b	0.1	3.4	3.2	7.1	109.0	122.9 ± 3.9	54.9	46.5	6.3
4b	0.1	0.7	3.2	1.5	27.3	32.8 ± 3.4	38.1	32.8	4.6
$p_T^{miss} > 200\,\mathrm{GeV}$	0.1	0.3	3.2	1.1	9.4	14.1 ± 3.3	16.2	27.4	4.3
$p_T^{miss} > 300\,\mathrm{GeV}$	0.0	0.1	0.0	0.4	1.1	1.7 ± 0.2	2.0	11.5	3.5
$p_T^{miss} > 450\,\mathrm{GeV}$	0.0	0.0	0.0	0.1	0.1	0.1 ± 0.1	0.0	1.1	2.0

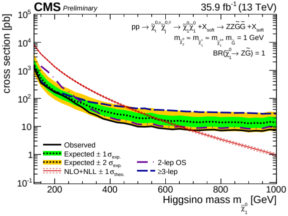


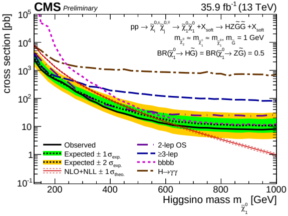
binned in $n_{b\text{-jets}}$, require small $\Delta m(h_1, h_2)$,

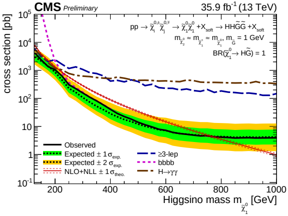
use avg. mass to define signal and sidebands for bg. estimate

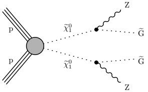
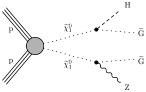
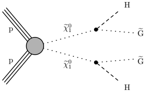
excluded Higgsino mass range: 230 – 770 GeV

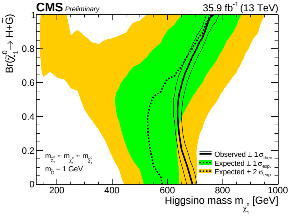
Search region	Global fit	Predictive fit	Observed yields	TChiHH (225,1)	TChiHH (400,1)	TChiHH (700,1)
			$150 < p_T^{miss} \leq 200\,\mathrm{GeV}$			
SBD, 2b	$1560.1^{+39.7}_{-38.5}$	—	1559	5.8	1.3	0.0
HIG, 2b	$656.2^{+25.2}_{-24.6}$	—	658	11.5	2.4	0.1
SBD, 3b	$140.3^{+10.8}_{-10.3}$	—	145	5.1	0.9	0.0
HIG, 3b	$57.7^{+5.5}_{-5.2}$	$61.2^{+8.4}_{-7.7}$	53	10.9	2.5	0.1
SBD, 4b	$48.1^{+6.4}_{-5.8}$	—	45	5.8	1.1	0.0
HIG, 4b	$21.9^{+3.5}_{-3.2}$	$19.0^{+4.6}_{-3.9}$	25	21.8	5.4	0.2
			$200 < p_T^{miss} \leq 300\,\mathrm{GeV}$			
SBD, 2b	$588.0^{+24.2}_{-23.5}$	—	585	3.0	3.2	0.1
HIG, 2b	$333.1^{+17.9}_{-17.6}$	—	336	6.0	6.6	0.3
SBD, 3b	$55.3^{+6.5}_{-5.9}$	—	61	2.2	2.6	0.1
HIG, 3b	$30.6^{+3.9}_{-3.6}$	$35.1^{+5.9}_{-5.5}$	25	5.0	6.2	0.3
SBD, 4b	$15.6^{+3.8}_{-3.1}$	—	13	2.4	3.3	0.1
HIG, 4b	$11.4^{+3.0}_{-2.5}$	$7.5^{+3.8}_{-2.7}$	14	14.3	15.7	0.8
			$300 < p_T^{miss} \leq 450\,\mathrm{GeV}$			
SBD, 2b	$72.4^{+8.7}_{-8.1}$	—	74	0.0	1.9	0.2
HIG, 2b	$40.6^{+6.3}_{-6.0}$	—	39	0.4	4.9	0.7
SBD, 3b	$5.7^{+2.2}_{-1.8}$	—	4	0.1	1.6	0.2
HIG, 3b	$3.3^{+1.4}_{-1.1}$	$2.1^{+1.4}_{-1.0}$	5	0.9	4.6	0.5
SBD, 4b	$1.9^{+1.4}_{-0.9}$	—	2	0.2	1.5	0.2
HIG, 4b	$1.1^{+0.8}_{-0.5}$	$1.1^{+1.0}_{-0.6}$	1	2.0	10.3	1.5
			$p_T^{miss} > 450\,\mathrm{GeV}$			
SBD, 2b	$5.4^{+2.5}_{-2.1}$	—	5	0.0	0.1	0.2
HIG, 2b	$4.6^{+2.2}_{-1.9}$	—	5	0.0	0.4	0.9
SBD, 3b	$0.6^{+0.8}_{-0.4}$	—	1	0.1	0.1	0.2
HIG, 3b	$0.4^{+0.6}_{-0.3}$	$1.0^{+1.6}_{-1.0}$	0	0.0	0.4	0.7
SBD, 4b	$0.0^{+0.3}_{-0.0}$	—	0	0.0	0.1	0.2
HIG, 4b	$0.0^{+0.3}_{-0.0}$	$0.0^{+1.2}_{-0.0}$	0	0.0	1.1	2.0

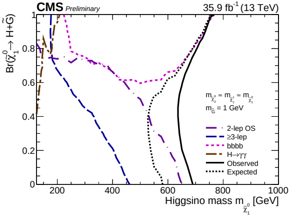

CMS Preliminary
35.9 fb-1 (13 TeV)
cross section [pb]
BR($\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$) = 1
Observed
Expected ± 1σexp.
Expected ± 2 σexp.
NLO+NLL ± 1σtheo.
2-lep OS
≥3-lep
Higgsino mass $m_{\tilde{\chi}_1^0}$ [GeV]

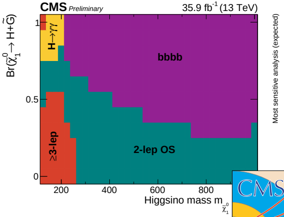

CMS Preliminary
35.9 fb-1 (13 TeV)
cross section [pb]
BR($\tilde{\chi}_1^0 \rightarrow H\tilde{G}$) = BR($\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$) = 0.5
Observed
Expected ± 1σexp.
Expected ± 2 σexp.
NLO+NLL ± 1σtheo.
2-lep OS
≥3-lep
bbbb
H→γγ
Higgsino mass $m_{\tilde{\chi}_1^0}$ [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
cross section [pb]
BR($\tilde{\chi}_1^0 \rightarrow H\tilde{G}$) = 1
Observed
Expected ± 1σexp.
Expected ± 2 σexp.
NLO+NLL ± 1σtheo.
≥3-lep
bbbb
H→γγ
Higgsino mass $m_{\tilde{\chi}_1^0}$ [GeV]

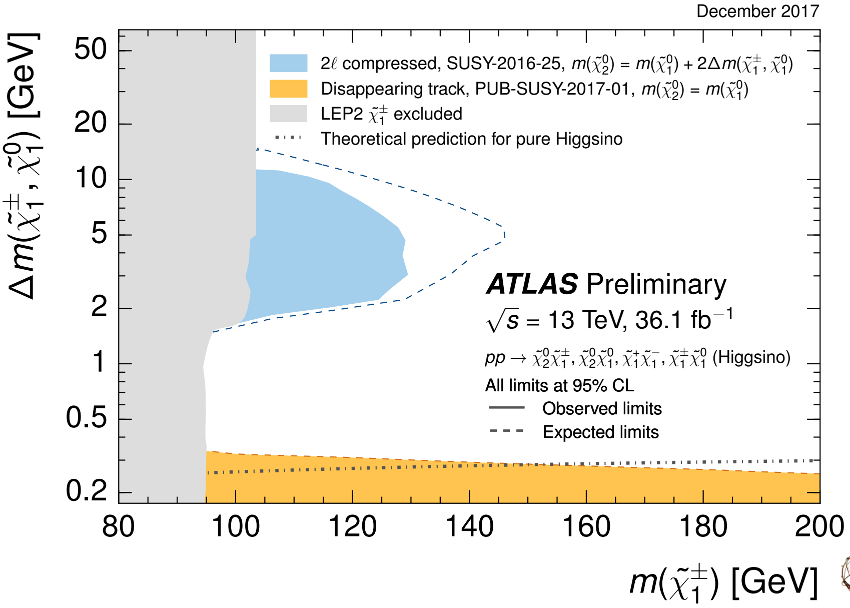

CMS Preliminary
35.9 fb-1 (13 TeV)
Br($\tilde{\chi}_1^0 \rightarrow H+\tilde{G}$)
$m_{\tilde{G}}$ = 1 GeV
Observed ± 1σtheo.
Expected ± 1σexp.
Expected ± 2 σexp.
Higgsino mass $m_{\tilde{\chi}_1^0}$ [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
Br($\tilde{\chi}_1^0 \rightarrow H+\tilde{G}$)
$m_{\tilde{G}}$ = 1 GeV
2-lep OS
≥3-lep
bbbb
H→γγ
Observed
Expected
Higgsino mass $m_{\tilde{\chi}_1^0}$ [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
Br($\tilde{\chi}_1^0 \rightarrow H+\tilde{G}$)
H→γγ
bbbb
≥3-lep
2-lep OS
Most sensitive analysis (expected)
Higgsino mass $m_{\tilde{\chi}_1^0}$

Extra Material

ATLAS Higgsino Summary (December 2017)



ATLAS SUSY Summary (December 2017)

ATLAS SUSY Searches* - 95% CL Lower Limits

December 2017

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

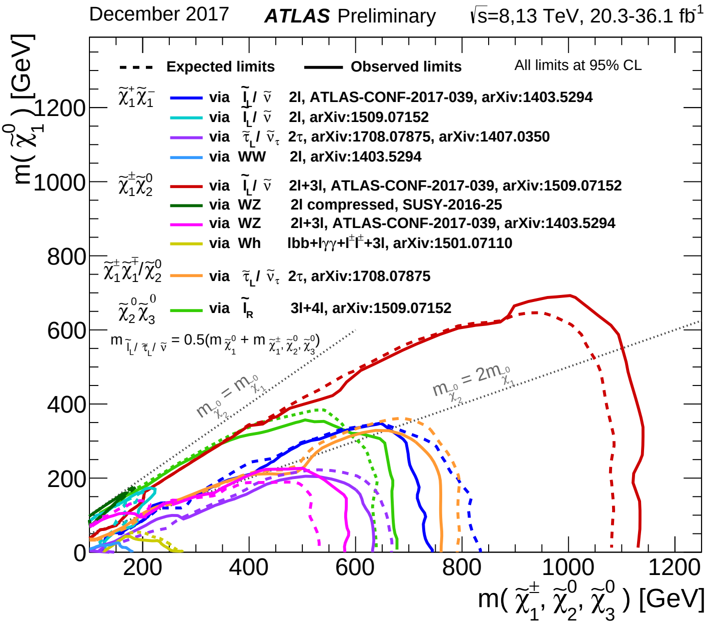
$\sqrt{s}$ = 7, 8 TeV | $\sqrt{s}$ = 13 TeV

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$ 1.57 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(1^{st}$ gen. $\tilde{q})=m(2^{nd}$ gen. $\tilde{q})$	1712.02332
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	36.1	$\tilde{q}$ 710 GeV	$m(\tilde{q})$-$m(\tilde{\chi}_1^0)$<5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.02 TeV	$m(\tilde{\chi}_1^0)$<200 GeV	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.01 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee,\mu\mu$	2 jets	Yes	14.7	$\tilde{g}$ 1.7 TeV	$m(\tilde{\chi}_1^0)$<300 GeV,	1611.05791
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	$\tilde{g}$ 1.87 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1706.03731
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$ 1.8 TeV	$m(\tilde{\chi}_1^0)$ <400 GeV	1708.02794
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$ 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	36.1	$\tilde{g}$ 2.15 TeV	$c\tau$(NLSP)<0.1 mm	ATLAS-CONF-2017-080
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	36.1	$\tilde{g}$ 2.05 TeV	$m(\tilde{\chi}_1^0)$=1700 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2017-080
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$ 1.92 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	1711.01901
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	36.1	$\tilde{g}$ 1.97 TeV	$m(\tilde{\chi}_1^0)$<200 GeV	1711.01901
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$ 950 GeV	$m(\tilde{\chi}_1^0)$<420 GeV	1708.09266
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$ 275-700 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_1^0)$+100 GeV	1706.03731
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 117-170 GeV, 200-720 GeV	$m(\tilde{\chi}_1^\pm)=2m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$ 90-198 GeV, 0.195-1.0 TeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	36.1	$\tilde{t}_1$ 90-430 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$=5 GeV	1711.03301
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$ 290-790 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	Yes	36.1	$\tilde{t}_2$ 320-880 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1706.03986
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	$\tilde{\ell}$ 90-500 GeV	$m(\tilde{\chi}_1^0)$=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	36.1	$\tilde{\chi}_1^\pm$ 750 GeV	$m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^\pm$ 760 GeV	$m(\tilde{\chi}_1^0)$=0, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1708.07875
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	36.1	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 1.13 TeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 580 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 270 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 635 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	36.1	$\tilde{W}$ 1.06 TeV	$c\tau$<1 mm	ATLAS-CONF-2017-080
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ 460 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1712.02118
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$ 495 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$ 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.57 TeV	$m(\tilde{\chi}_1^0)$=100 GeV, τ>10 ns	1604.04520
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$	displ. vtx	-	Yes	32.8	$\tilde{g}$ 2.37 TeV	$\tau(\tilde{g})$=0.17 ns, $m(\tilde{\chi}_1^0)$ = 100 GeV	1710.04901
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 440 GeV	1<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$ 1.9 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.45 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$ 1.14 TeV	$m(\tilde{\chi}_1^0)$>400GeV, $\lambda_{12k}\neq0$ (k = 1, 2)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	36.1	$\tilde{g}$ 1.875 TeV	$m(\tilde{\chi}_1^0)$=1075 GeV	SUSY-2016-22
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 2.1 TeV	$m(\tilde{\chi}_1^0)$= 1 TeV, $\lambda_{112}\neq0$	1704.08493
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 1.65 TeV	$m(\tilde{t}_1)$= 1 TeV, $\lambda_{323}\neq0$	1704.08493
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde{t}_1$ 100-470 GeV, 480-610 GeV		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	36.1	$\tilde{t}_1$ 0.4-1.45 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	1710.05544
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

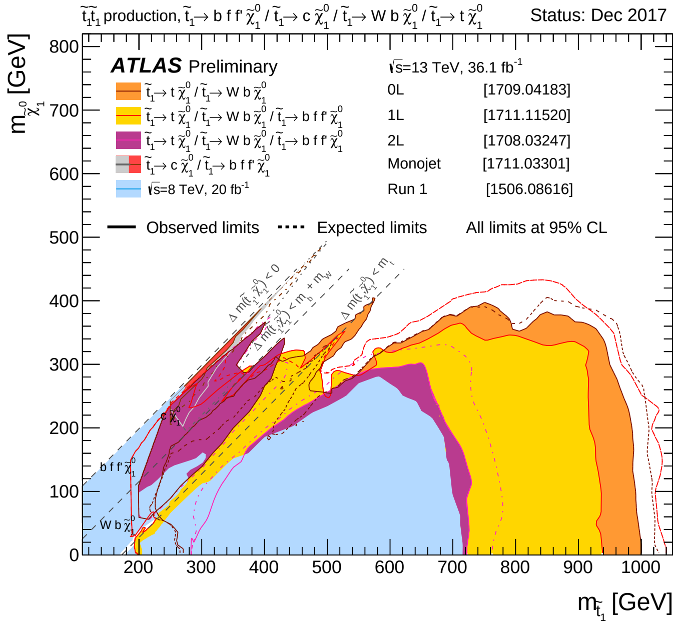
Mass scale [TeV] (10^{-1} … 1)

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

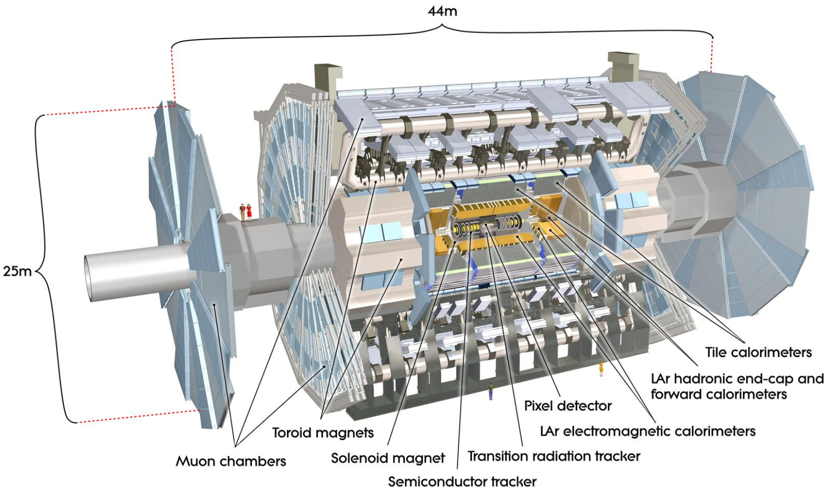
ATLAS EWK Summary Plot (December 2017)



ATLAS Stop Summary Plot (December 2017)



The ATLAS Detector



SUSY Models

mSUGRA / CMSSM Parameters

- $\rightarrow$ 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
- NUHM2: adds m_{H_u}, m_{H_d}, trade for μ, m_A

GMSB Parameters

- $\rightarrow$ 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
  $\Rightarrow$ 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
  $\Rightarrow$ light stop and light gluino as only light (relevant) coloured sparticle
- some additional mechanism needed (as in GMSB) to produce "correct" Higgs mass