Searches for SUSY in Final States with Photons in ATLAS

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SUSY with Photons

- Photon signatures are common in Gauge Mediated Supersymmetry Breaking (GMSB) with neutralino NLSPs

- GMSB breaks SUSY via intermediate-scale messenger fields that are charged under SM gauge interactions
  - Naturally protects SM flavor symmetry → No FCNC
  - Gravitino ($\tilde{G}$) is always the LSP
    - Mass in eV-keV range
    - Non-interacting → Large E_T^{Miss}
  - NLSP can be $\tilde{\chi}_1^0$, $\tilde{\tau}$, or other slepton(s) in minimal GMSB
    - Decays to $\tilde{G}$ and SM partner of NLSP
    - Collider signature depends on the properties of the NLSP
    - Lifetime of NLSP is a free parameter → Decay can be prompt or displaced

Gauge Mediated Symmetry Breaking (GMSB)

- Minimal GMSB has only a few parameters
  - $\Lambda,\ \mathrm{M_{MES}},\ \mathrm{N_5},\ \tan(\beta),\ \mathrm{C_{grav}},\ \mathrm{sign}(\mu)$
  - Results in relatively few potential mass hierarchies
  - NLSP neutralino is almost always purely bino (superpartner to B field)

- There is much more freedom in the mass hierarchies of General Gauge Mediation (GGM) models
  - Superpartner mass parameters are largely independent
  - Any MSSM superpartner can be NLSP
  - An NLSP neutralino can be a mixture of bino, wino, and higgsino
    - Neutralino mixing depends on the parameters $\mathrm{M_1},\ \mathrm{M_2},\ \mu,\ \tan\beta$
    - Depending on the relationship between these parameters, several interesting photon phenomenologies can occur
    - In case of wino or higgsino NLSP, chargino has mass very close to mass of lightest neutralino and can be co-NLSP

GGM Photon Scenarios

Bino, wino, and higgsinos mix to form neutralino mass eigenstates

$$(\tilde{B}^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0) \rightarrow (\chi_1^0, \chi_2^0, \chi_3^0, \chi_4^0)$$

Possible decay modes:

$$\tilde{\chi}_1^0 \rightarrow (\gamma, Z, h) + \tilde{G}$$

Wino-like NLSP

- $M_2 << M_1, \mu$
- $\tilde{\chi}_1^{\pm}$ is co-NLSP
- Dominant decays: $\tilde{\chi}_1^0 \rightarrow (\gamma, Z) + \tilde{G}$, $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} + \tilde{G}$
- Photon+Lepton+E_T^{Miss} signature

Bino-like NLSP

- $M_1 << M_2, \mu$
- Dominant decay: $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
- Diphoton+E_T^{Miss} signature

Higgsino-bino admixture NLSP

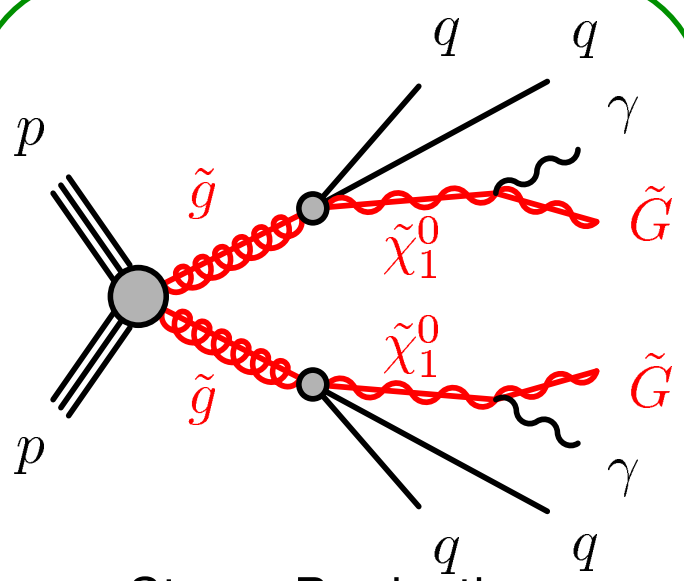
- $M_1 \approx |\mu| << M_2$
- Dominant decays ($\mu > 0$):
  - $\tilde{\chi}_1^0 \rightarrow (\gamma, Z) + \tilde{G}$
  - Photon+jets+E_T^{Miss} signature
- Dominant decays ($\mu < 0$):
  - $\tilde{\chi}_1^0 \rightarrow (\gamma, h) + \tilde{G}$
  - Photon+b-jets+E_T^{Miss} signature

Diphoton + E_T^{Miss} (prompt)

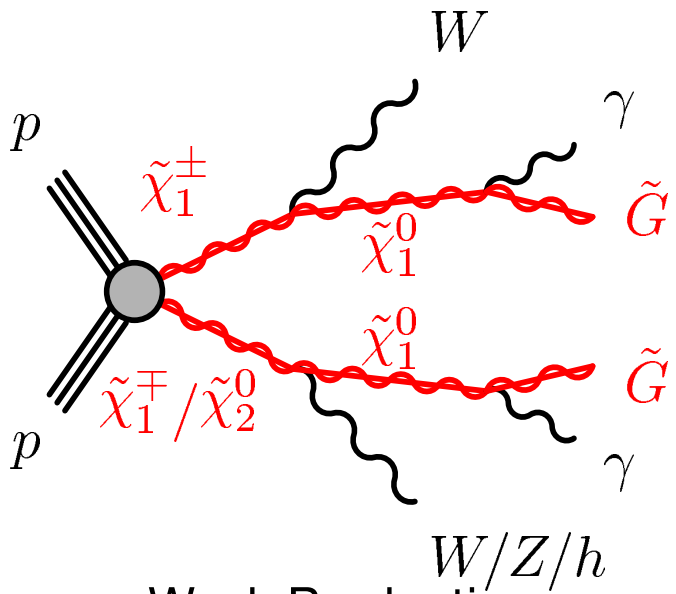
ATLAS-CONF-2014-001 (20.3 fb^{-1} @ 8 TeV)

- Bino-like NLSP → Decay chain on both sides of event have $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$
  - Diphoton+E_T^{Miss} signature
- NLSP decays promptly ($c\tau_{NLSP} < 0.1$mm)
- Event selection:
  - 5 Signal Regions
    - 2 regions focused on strong production (SP1, SP2)
      - $m_{\tilde{g}} \approx 1300$ GeV
    - 2 regions focused on weak production (WP1, WP2)
      - $m_{\tilde{\chi}_2^0} \approx m_{\tilde{\chi}_1^\pm} \approx 600$ GeV
    - 1 model-independent region (MIS)
  - Each signal region requires ≥ 2 isolated photons w/ $p_T > 75$ GeV

	SP1	SP2	WP1	WP2	MIS
$\Delta\phi_\gamma^{min} >$	0.5	0.0	0.5	0.0	0.0
$\Delta\phi_{jet}^{min} >$	0.5	0.5	0.5	0.5	0.5
$M_{eff} > (H_T >)$ (GeV)	1500	1800	(400)	(600)	0
$E_T^{miss} >$ (GeV)	250	150	200	150	250



Strong Production



Weak Production

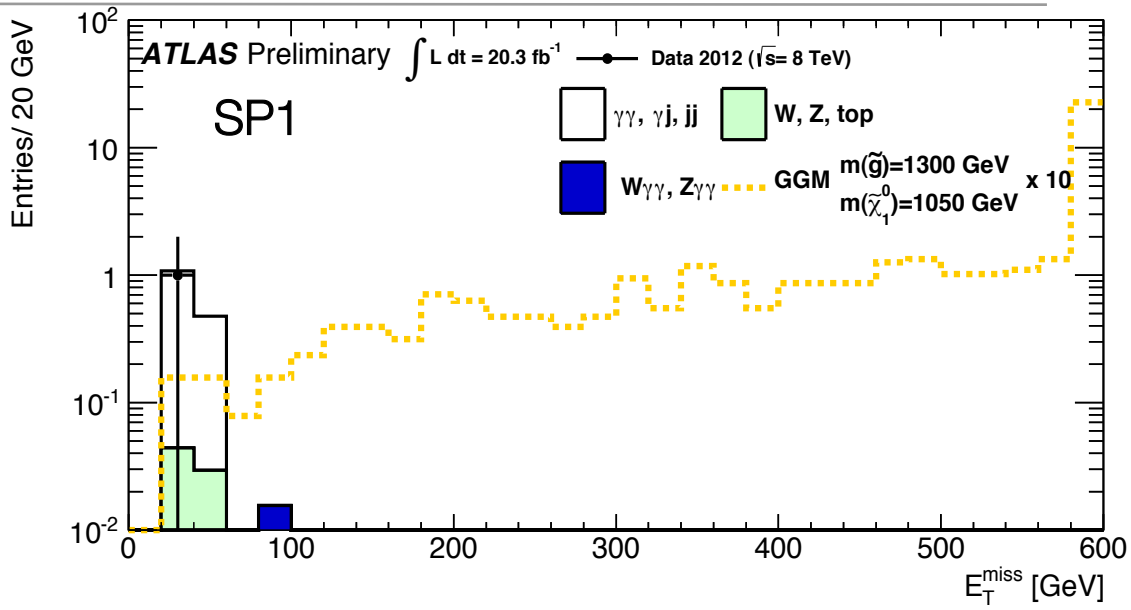
Diphoton + E_T^{Miss} (prompt)

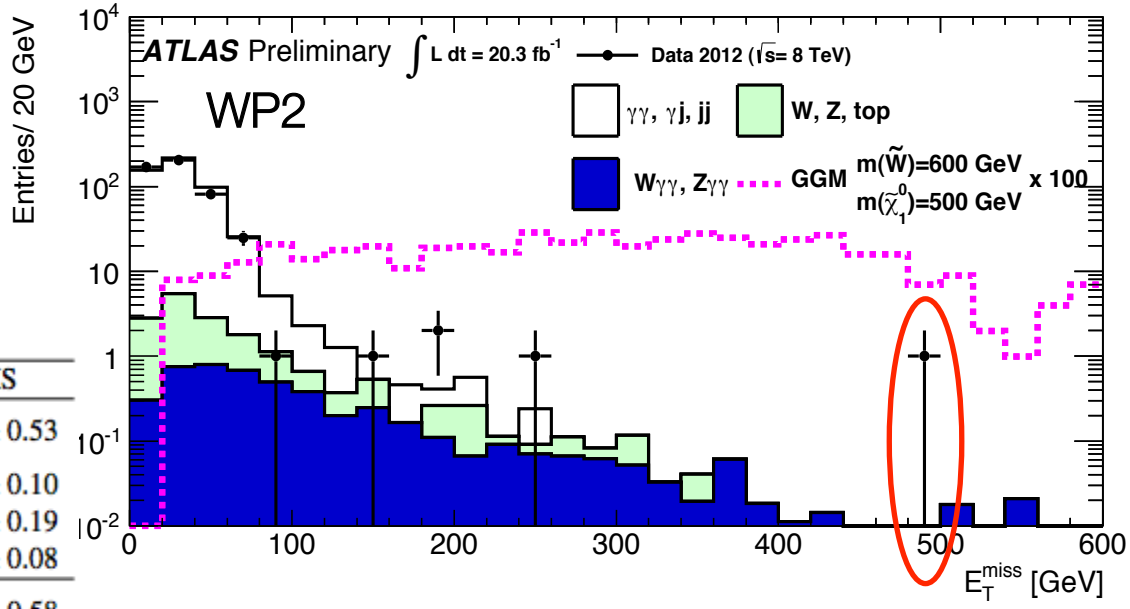
ATLAS-CONF-2014-001 (20.3 fb^{-1} @ 8 TeV)

Dominant backgrounds

- QCD multi-jet, γ+jet, γγ
  - loose γ CR normalized in low E_T^{Miss} region
- Electroweak W+X, Z+X, $t\bar{t}$
  - electron CR normalized using e→γ fake rate scale factor found with tag & probe of Z mass peak
- Irreducible Zγγ, Wγγ
  - MC, with data-driven normalization for Wγγ

Background	SP1	SP2	WP1	WP2	MIS
QCD	$0.00^{+0.20}_{-0.00}$	$0.22^{+0.53}_{-0.22}$	0.29 ± 0.29	0.89 ± 0.60	0.73 ± 0.53
Electroweak	< 0.02	0.02 ± 0.02	0.15 ± 0.07	0.67 ± 0.22	0.24 ± 0.10
$W(\to \ell\nu) + \gamma\gamma$	0.03 ± 0.02	0.02 ± 0.01	0.44 ± 0.18	0.74 ± 0.27	0.47 ± 0.19
$Z(\to \nu\bar{\nu}) + \gamma\gamma$	< 0.01	< 0.01	0.13 ± 0.07	0.08 ± 0.04	0.15 ± 0.08
Total	$0.03^{+0.20}_{-0.02}$	$0.26^{+0.53}_{-0.22}$	1.01 ± 0.36	2.38 ± 0.69	1.59 ± 0.58
Observed events	0	0	1	5	2





Diphoton + E_T^{Miss} (prompt)

ATLAS-CONF-2014-001 (20.3 fb^{-1} @ 8 TeV)

Run 201120

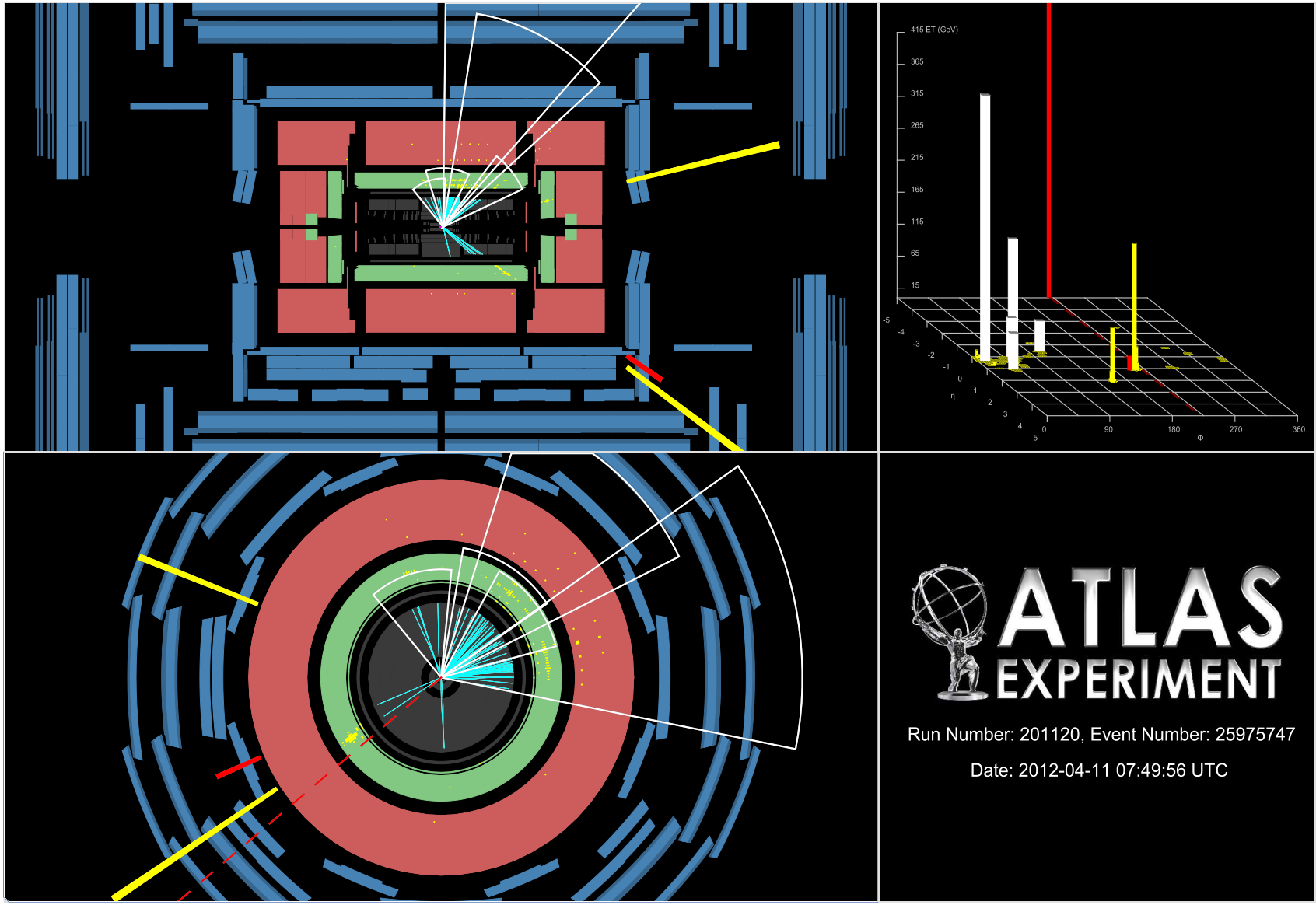
Event 25975747

$p_T^{\gamma 1}$ = 197 GeV

$p_T^{\gamma 2}$ = 84 GeV

E_T^{Miss} = 478 GeV

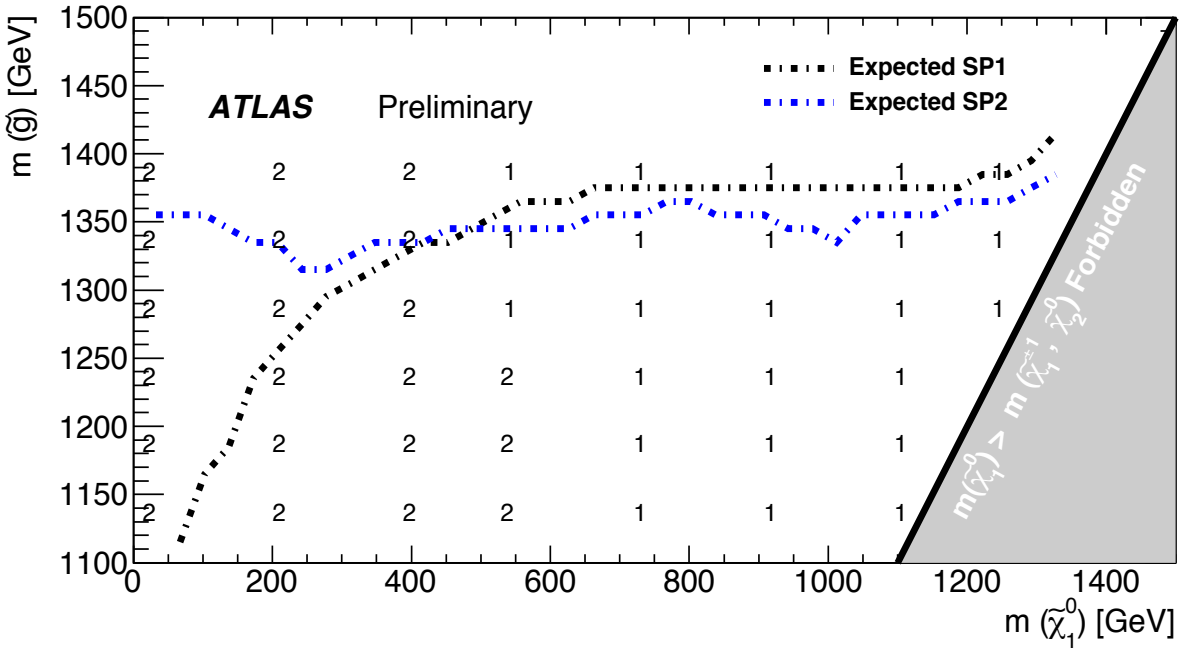
5 jets (p_T > 30 GeV)

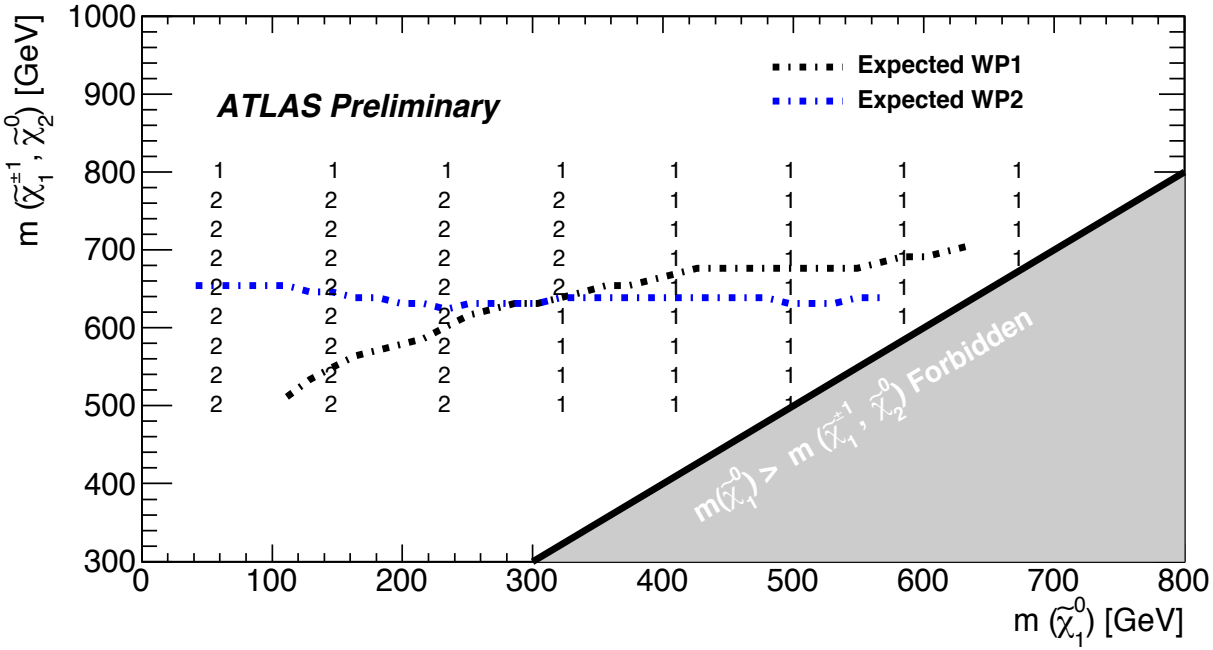


Diphoton + E_T^{Miss} (prompt)

ATLAS-CONF-2014-001 (20.3 fb^{-1} @ 8 TeV)

- No sign of new physics despite slight excess in WP2
  - 5 events with 2.38 ± 0.69 expected has 13% probability
- Set 95% CL in GGM planes
  - $\sigma_{vis} < 0.15$ fb (SP1)
  - $\sigma_{vis} < 0.14$ fb (SP2)
  - $\sigma_{vis} < 0.19$ fb (WP1)
  - $\sigma_{vis} < 0.41$ fb (WP2)
  - $\sigma_{vis} < 0.23$ fb (MIS)





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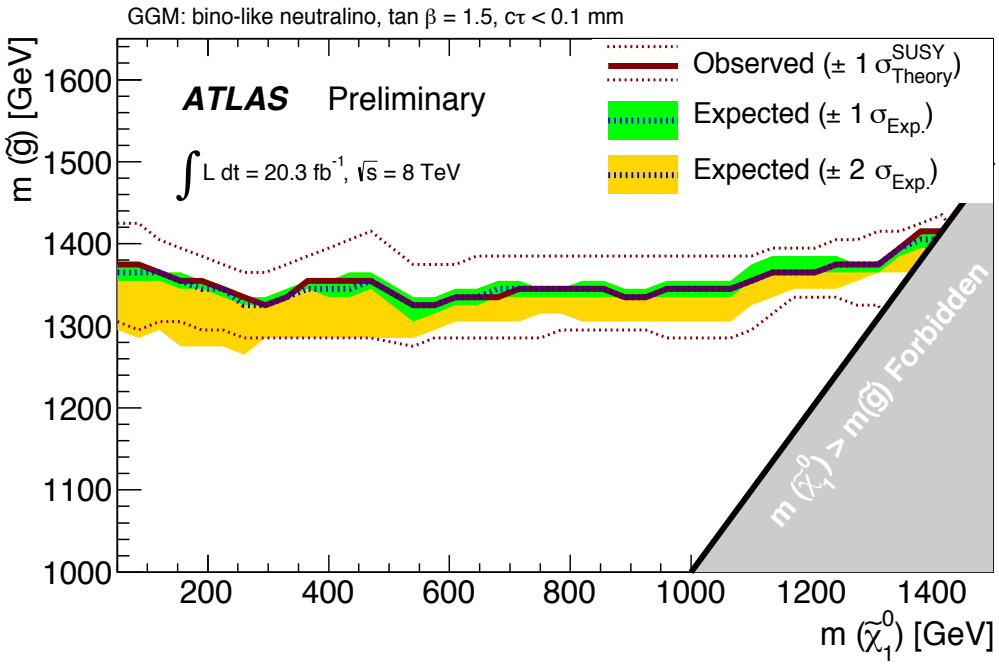
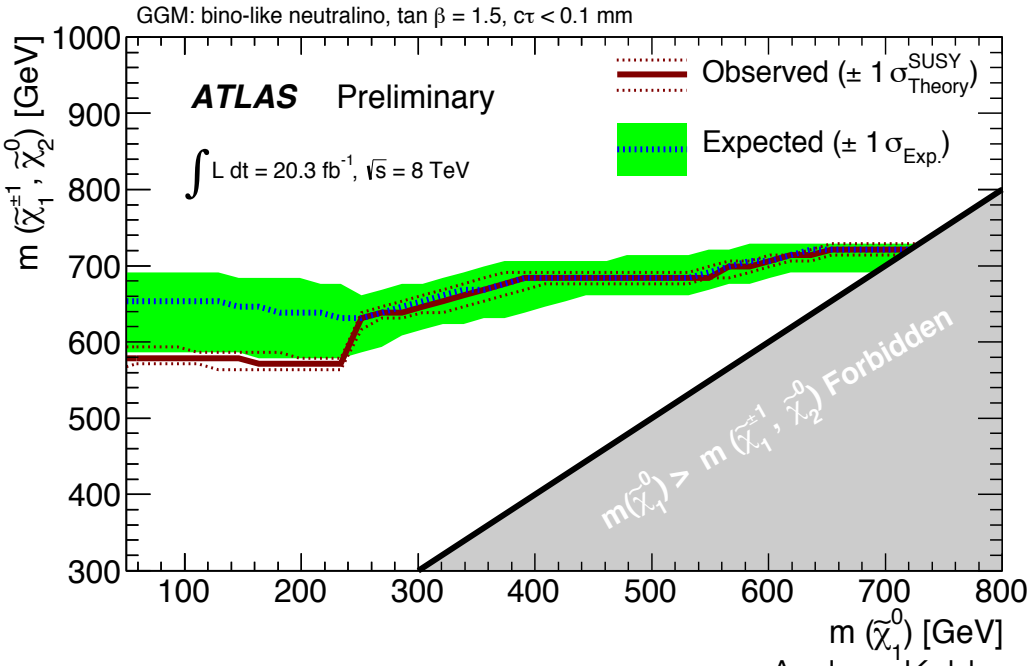
  - σ_{vis} < 0.23 fb (MIS)
- Gluino mass > 1280 GeV in gluino-bino plane
- Wino mass > 570 GeV in wino-bino plane

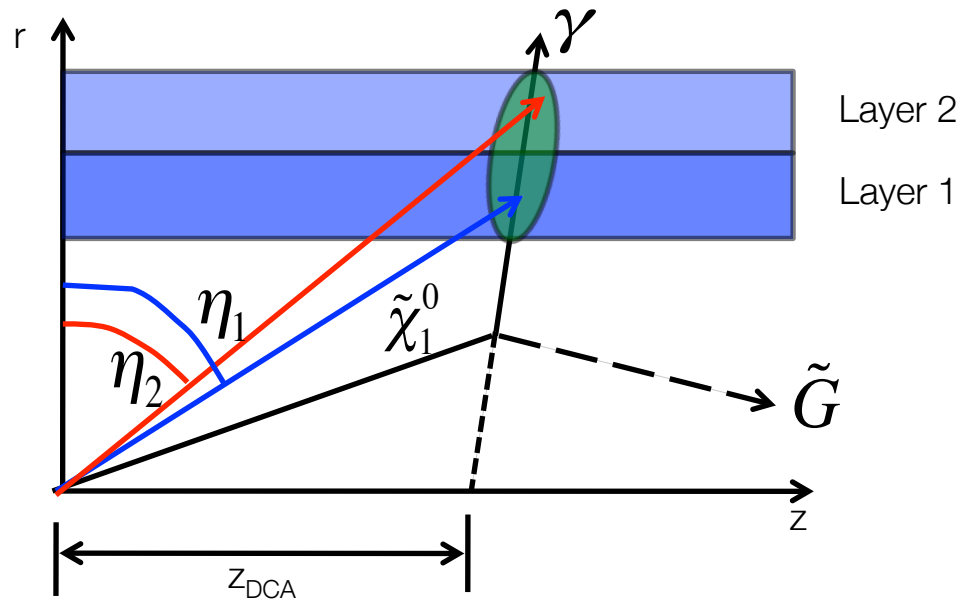


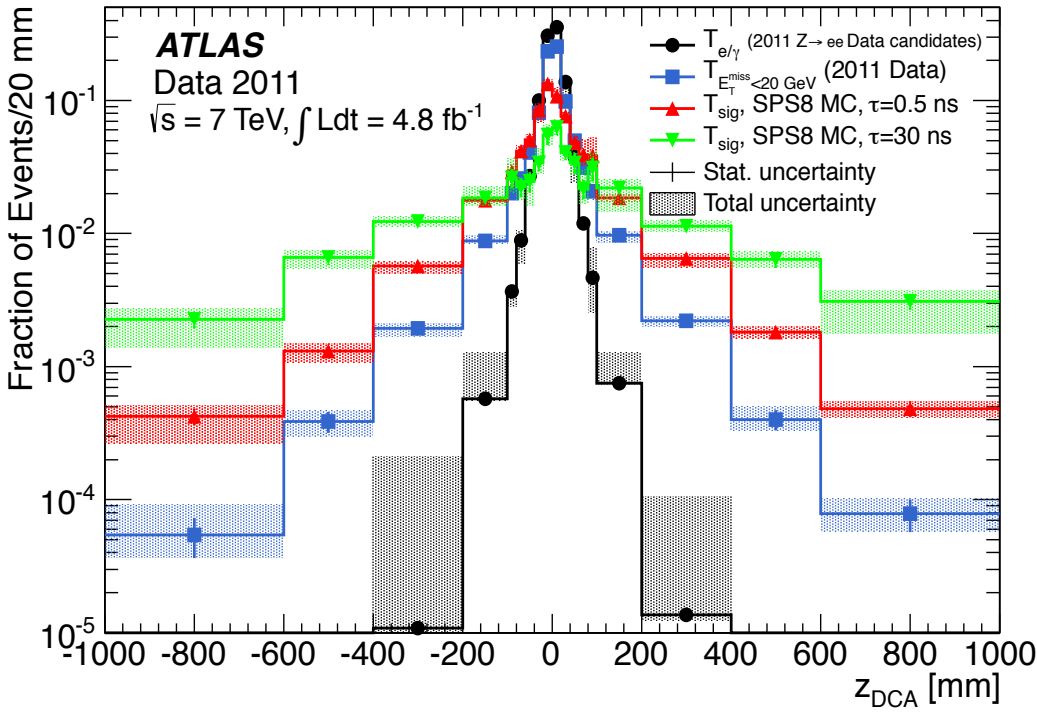


Diphoton + E_T^{Miss} (non-prompt)

Phys. Rev. D 88, 012001 (2013) (4.8 fb^{-1} @ 7 TeV)

- Bino-like NLSP with finite lifetime
  - Photon(s) that does not point to beamspot in final state
  - Takes advantage of pointing and timing resolutions of ATLAS EM calorimeter
- Event selection
  - 2 isolated photons w/ $p_T > 50$ GeV
  - 'TL' ID:
    - 1 tight photon w/ $|\eta| < 2.37$
    - 1 loose photon w/ $|\eta| < 1.37$
  - $E_T^{Miss} > 75$ GeV
- Dominant backgrounds
  - Prompt photon/misidentified electron
    - Z_{ee} template
  - Misidentified jet
    - Low E_T^{Miss} control region
- Fit z_{DCA} (distance of closest approach) of loose photon to S+B template

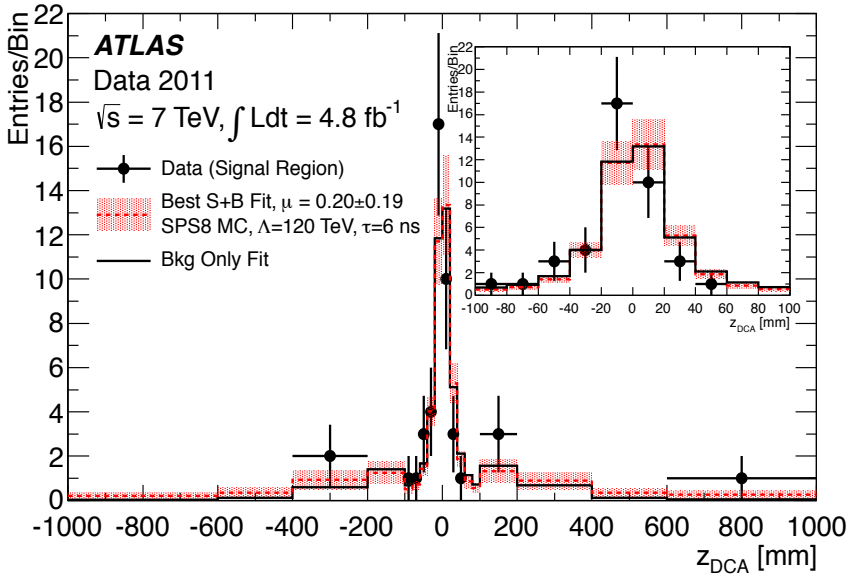




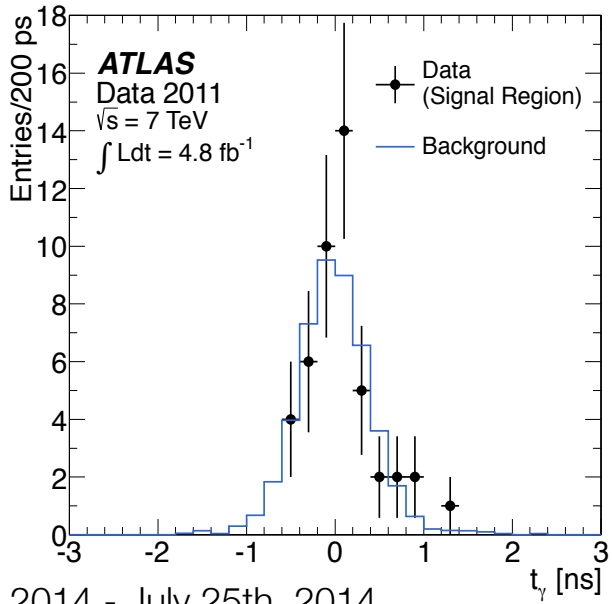
Diphoton + E_T^{Miss} (non-prompt)

Phys. Rev. D 88, 012001 (2013) (4.8 fb^{-1} @ 7 TeV)

No excess observed

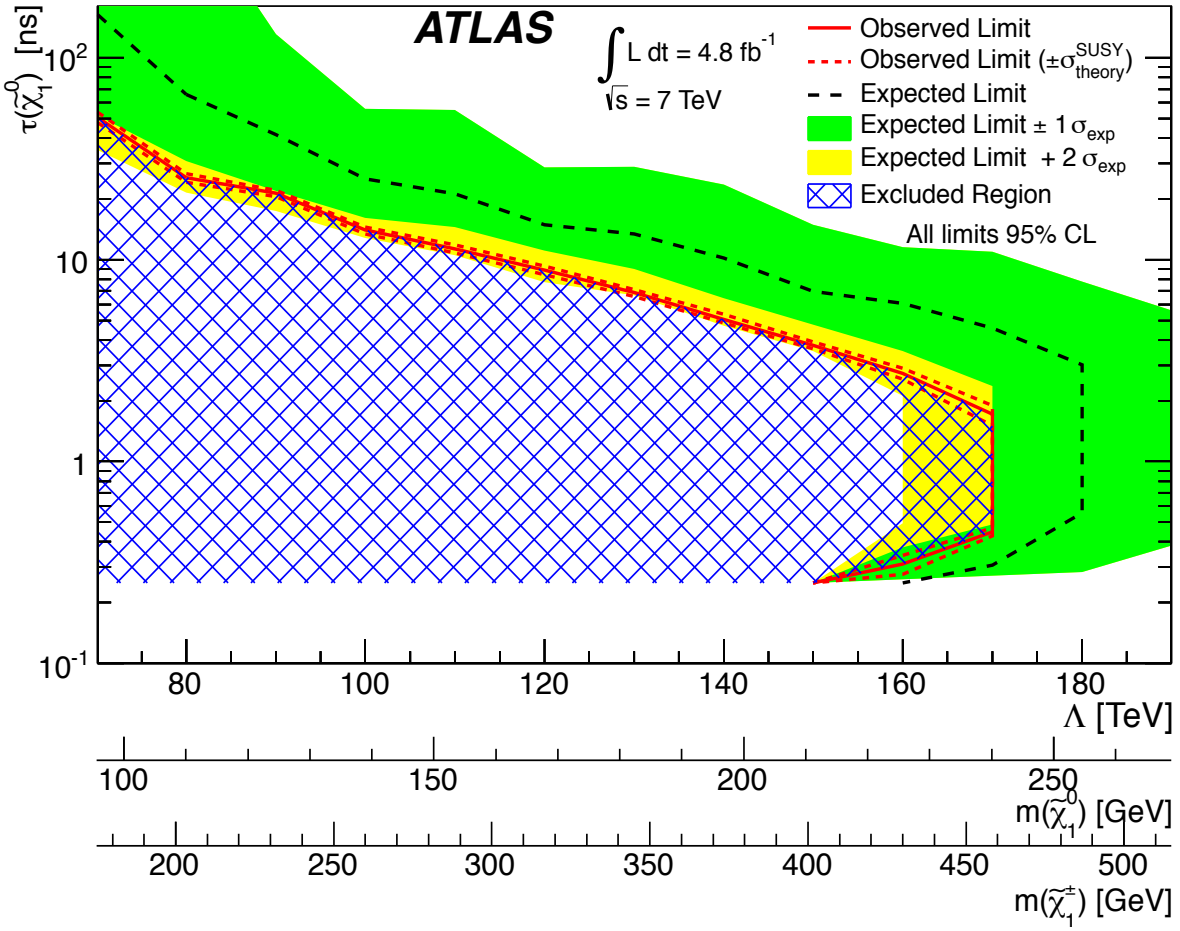


Use timing as cross-check



Interpret using GMSB SPS8 benchmark

- Λ vs. $\tau(\chi_1^0)$
- At Λ = 120 TeV
  - Expected limit: $\tau > 14.6$ ns
  - Observed limit: $\tau > 8.7$ ns

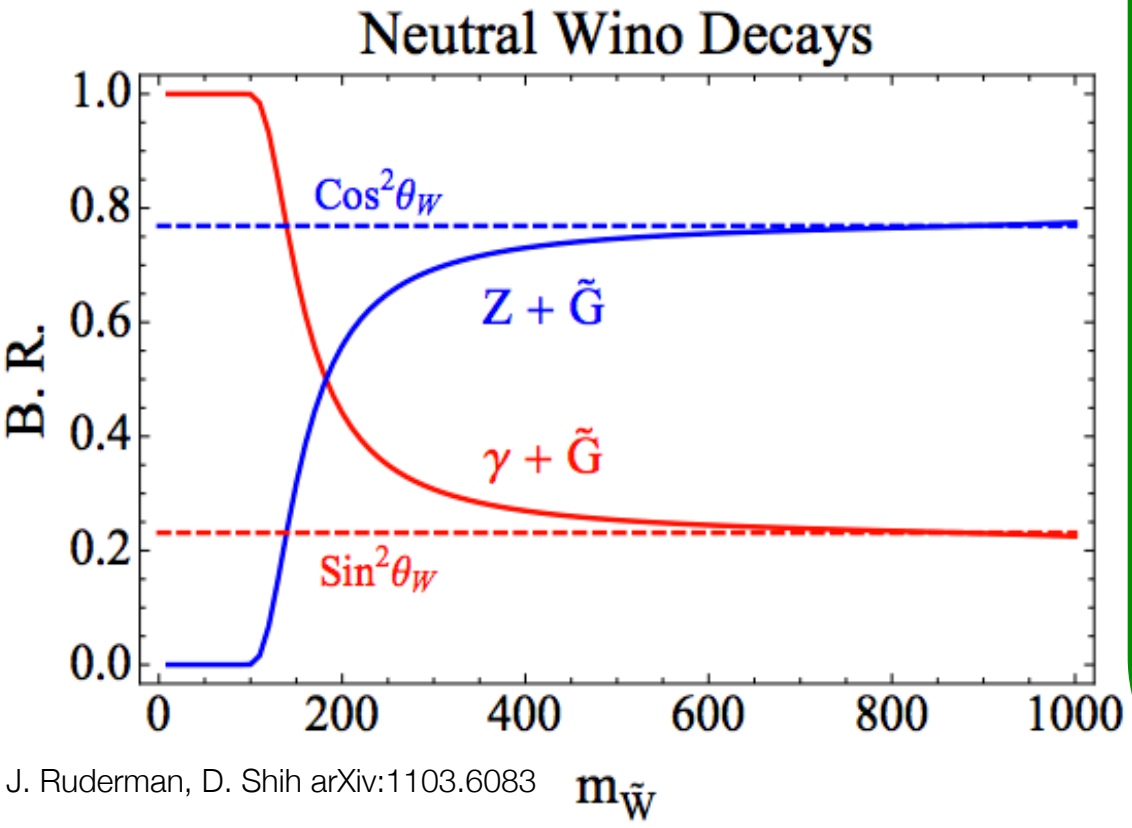


Photon + Lepton + E_T^{Miss}

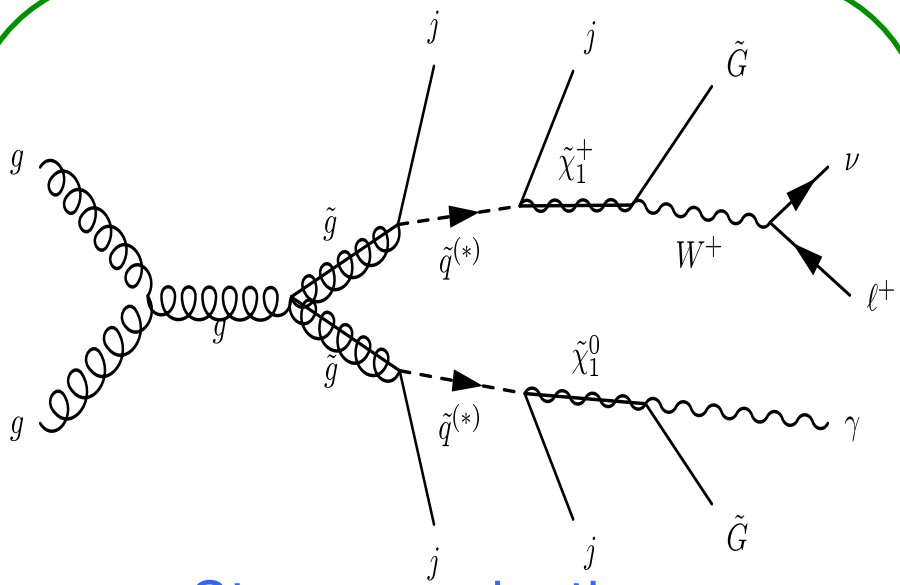
ATLAS-CONF-2012-144 (4.8 fb^{-1} @ 7 TeV)

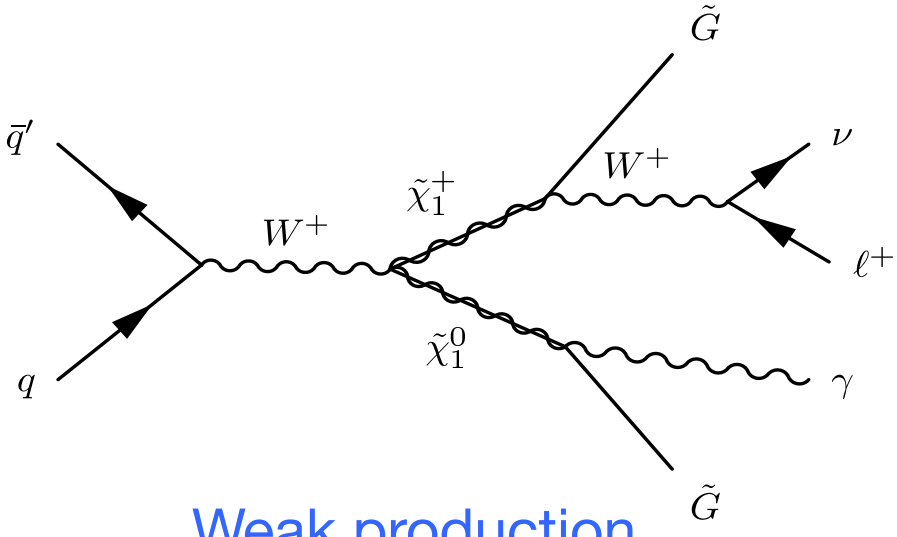
GGM Wino-like NLSP

- χ_1^0 and $\chi_1^\pm$ are co-NLSPs
- $\tilde{\chi}_1^0 \rightarrow (\gamma, Z) + \tilde{G}$
- $\tilde{\chi}_1^\pm \rightarrow W^\pm + \tilde{G}$
- Search for $\gamma + l + E_T^{Miss}$



J. Ruderman, D. Shih arXiv:1103.6083





Photon + Lepton + E_T^{Miss}

ATLAS-CONF-2012-144 (4.8 fb^{-1} @ 7 TeV)

Event Selection

Electron Channel

≥1 γ w/ p_T > 100 GeV

≥1 e w/ p_T > 25 GeV

no μ w/ p_T > 25 GeV

$|m_{e\gamma}-m_Z|$ > 15 GeV

$\Delta R(e, \gamma) > 0.7$

$M_T(e, E_T^{Miss})$ > 100 GeV

E_T^{Miss} > 100 GeV

Muon Channel

≥1 γ w/ p_T > 85 GeV

≥1 μ w/ p_T > 25 GeV

no e w/ p_T > 25 GeV

$\Delta R(\mu, \gamma) > 0.7$

$M_T(\mu, E_T^{Miss})$ > 100 GeV

E_T^{Miss} > 100 GeV

Dominant Backgrounds

Wγ, $t\bar{t}\gamma$, full lep. $t\bar{t}$

MC normalized in control regions

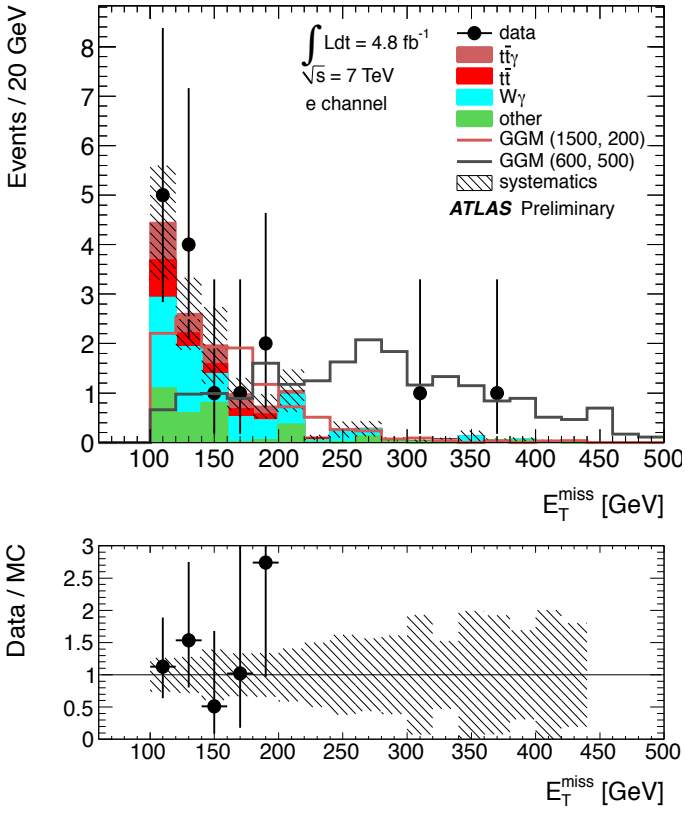
W+jets, semi lep. $t\bar{t}$

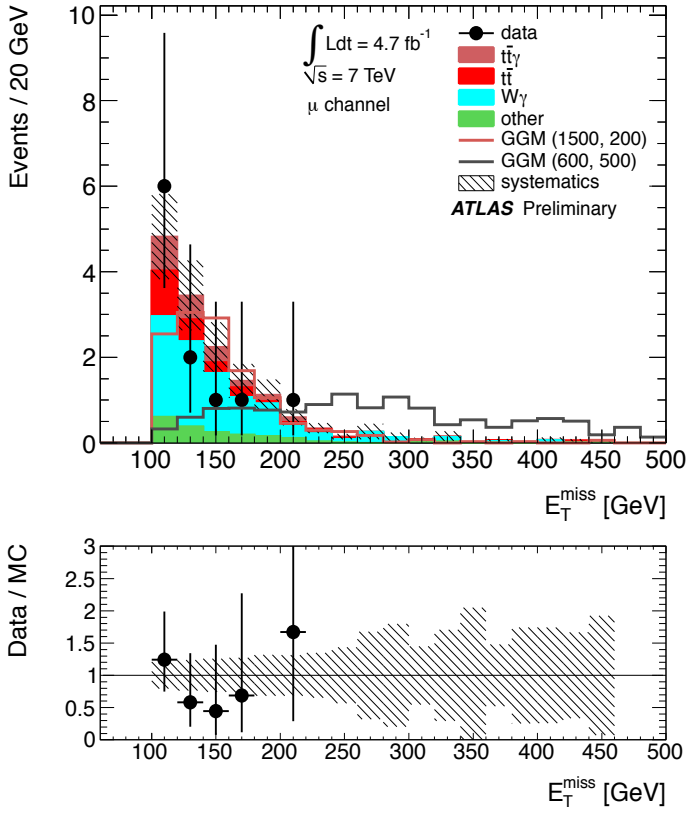
ABCD method using γ iso. and γ ID

γ+jet

Matrix method with tight/loose samples

Other minor contributions from MC





Photon + Lepton + E_T^{Miss}

ATLAS-CONF-2012-144 (4.8 fb^{-1} @ 7 TeV)

e-channel:

- Expected 13.0 ± 3.4 events
- Observed 15 events

μ-channel:

- Expected 15.1 ± 3.6 events
- Observed 11 events

Set limit at 95% CL:

e-channel: $\sigma_{vis} < 2.7$ fb

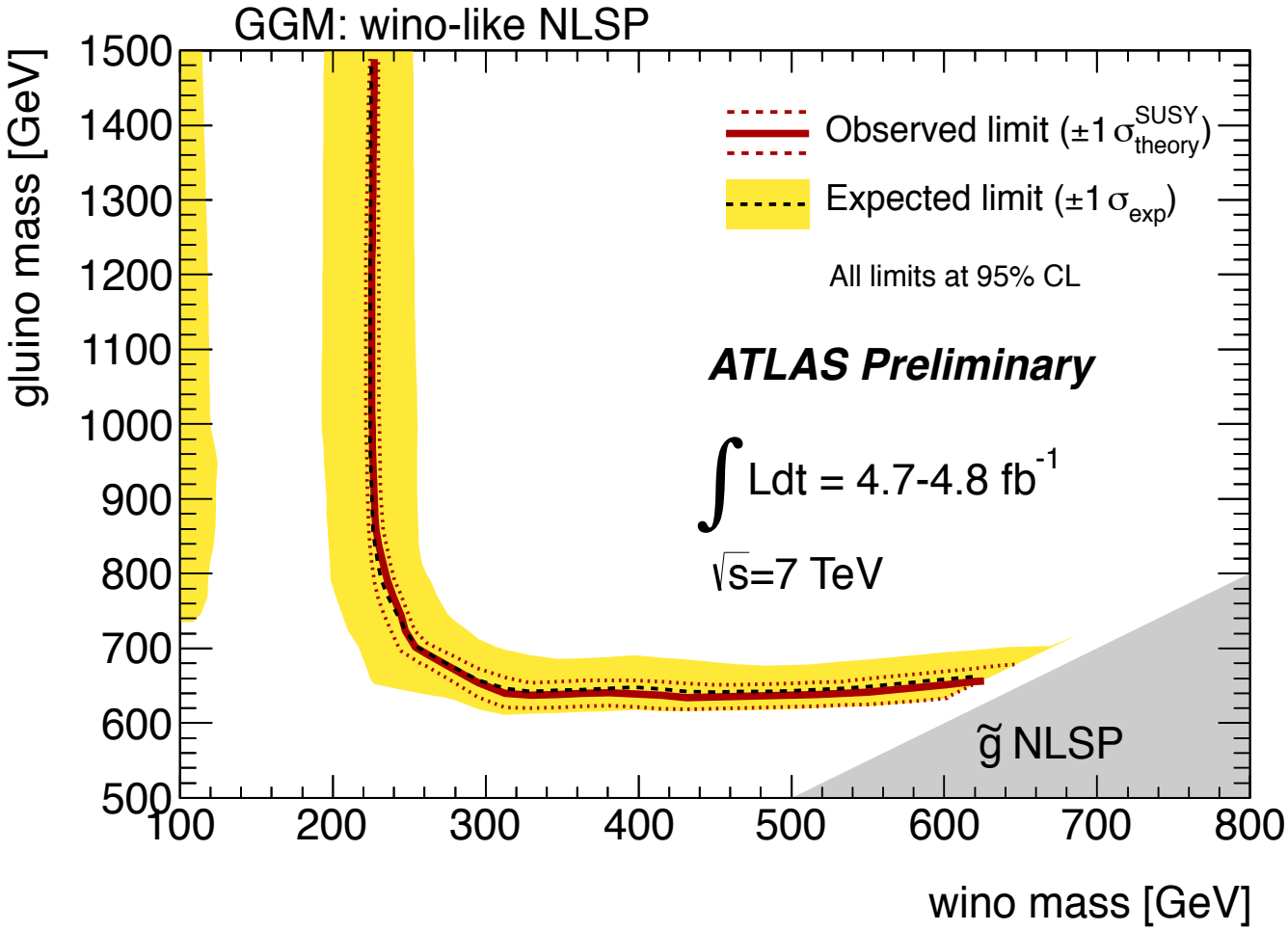
μ-channel: $\sigma_{vis} < 1.8$ fb

Interpretation:

Combine channels in gluino-wino GGM plane

gluino mass > 619 GeV for any wino mass

wino mass > 221 GeV for any gluino mass

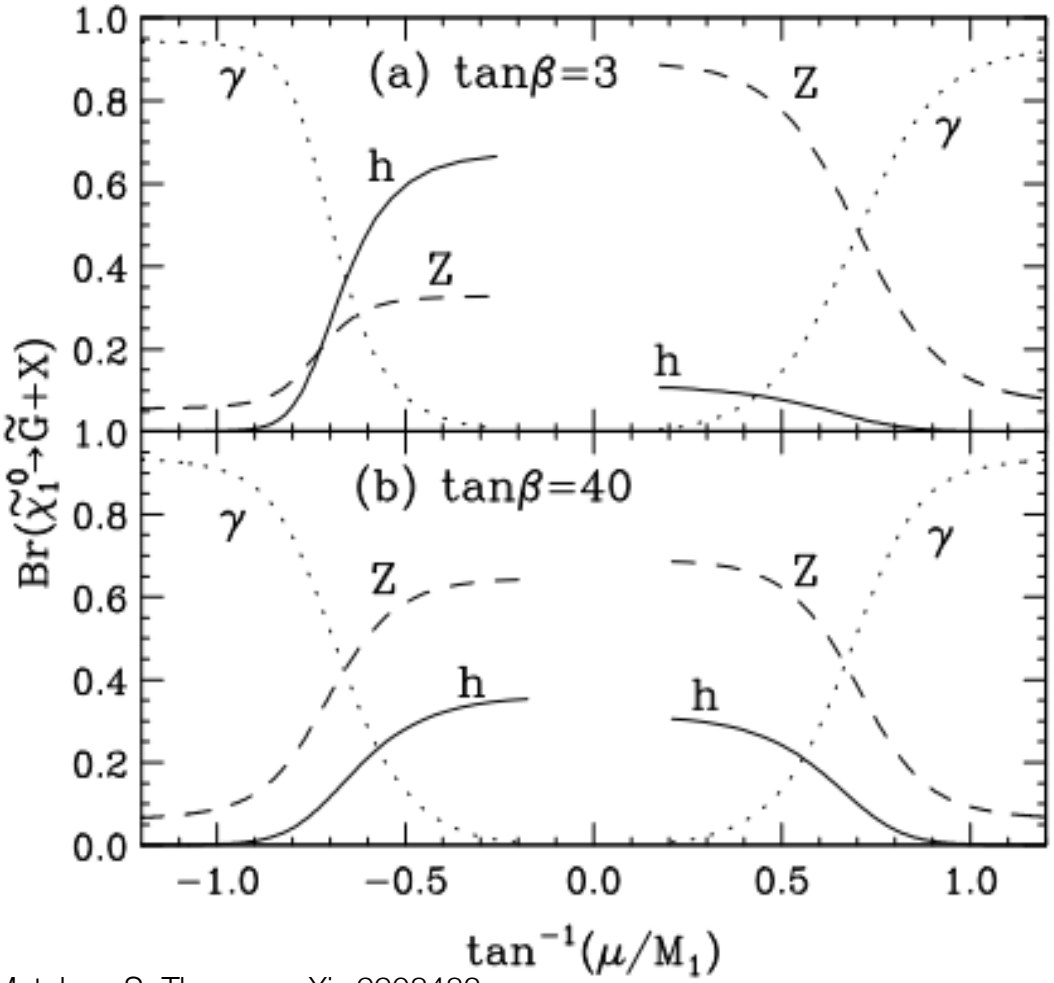


Photon + b-jet + E_T^{Miss}

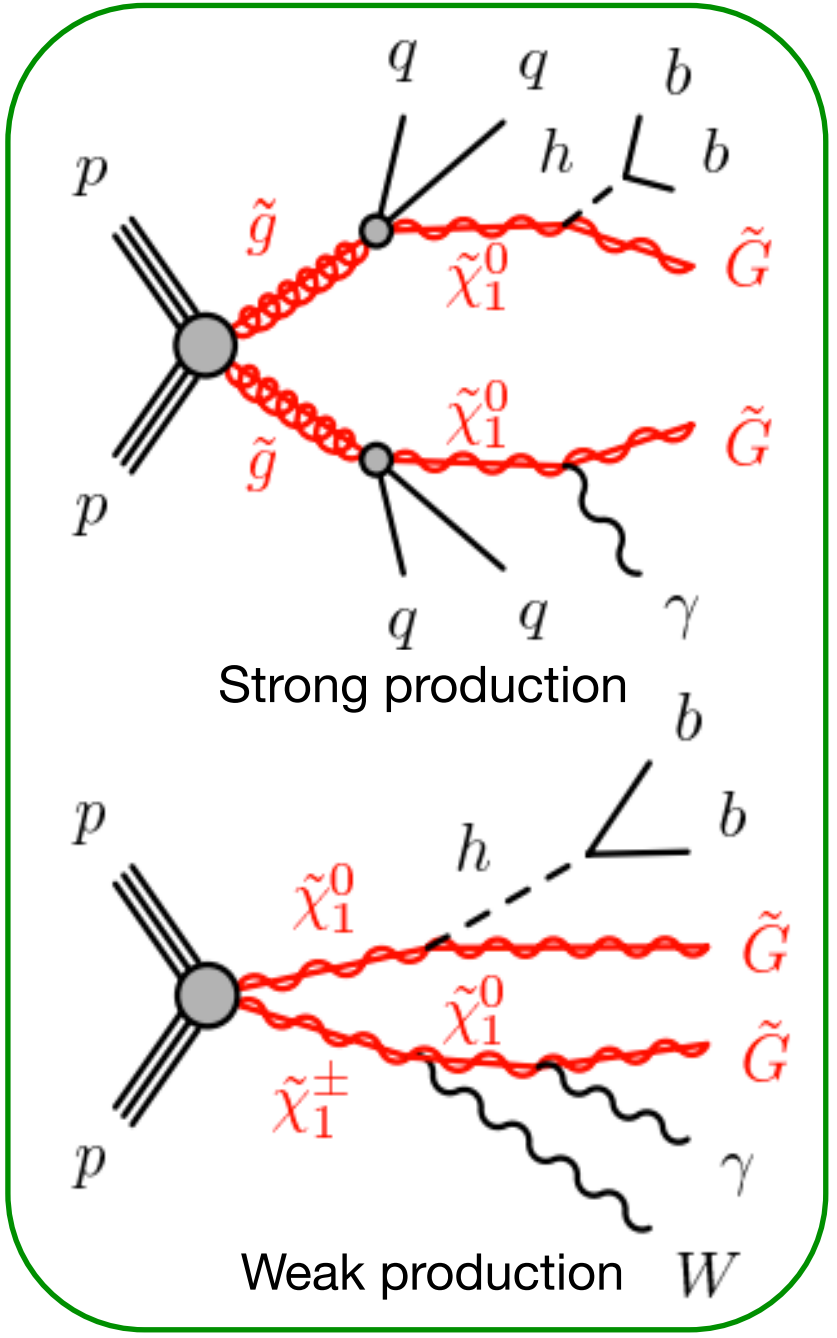
Phys. Lett. B 719 (2013) 261-279 (4.7 fb-1 @ 7 TeV)

GGM Higgsino-Bino admixture NLSP

- $\mu < 0$, $M_1 \approx |\mu|$: $\tilde{\chi}_1^0 \rightarrow (\gamma, h) + \tilde{G}$, $h \rightarrow b\bar{b}$
- Search for γ + b-jet(s) + E_T^{Miss}



K. Matchev, S. Thomas arXiv:9908482



Photon + b-jet + E_T^{Miss}

Phys. Lett. B 719 (2013) 261-279 (4.7 fb-1 @ 7 TeV)

Event Selection

1γ w/ $p_T > 125$ GeV

Veto on 2nd γ w/ $p_T > 50$ GeV

≥ 2 jets w/ $p_T > 20$ GeV, ≥ 1 b-tagged

Lepton veto

$\Delta\phi(j_{1,2}, E_T^{Miss}) > 0.4$

$M_T(\gamma, E_T^{Miss}) > 100$ GeV

$E_T^{Miss} > 150$ GeV

Major backgrounds

QCD multi-jet (including γ+jet)

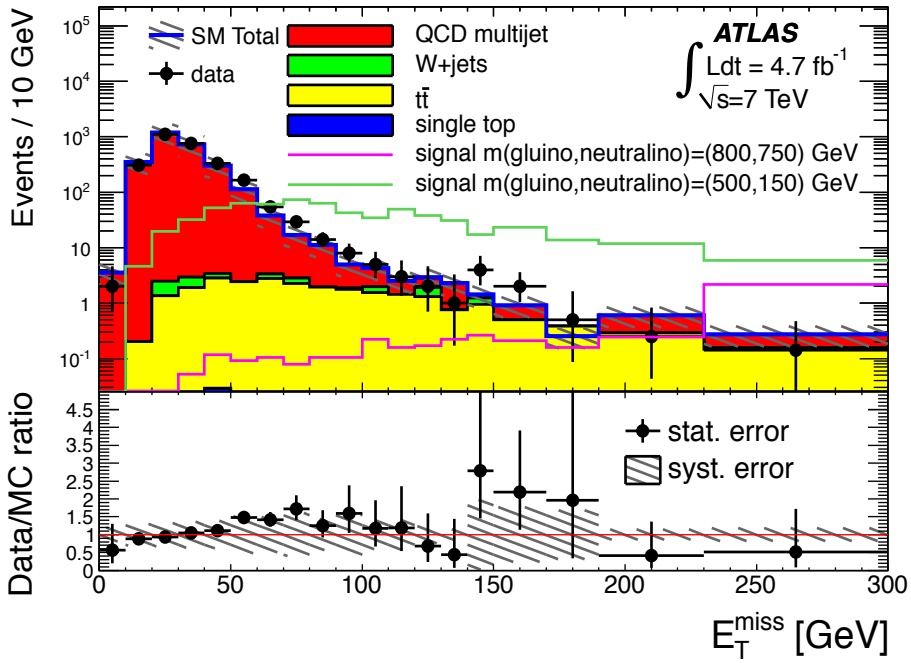
- ABCD method using low E_T^{Miss} and 0 b-tag regions

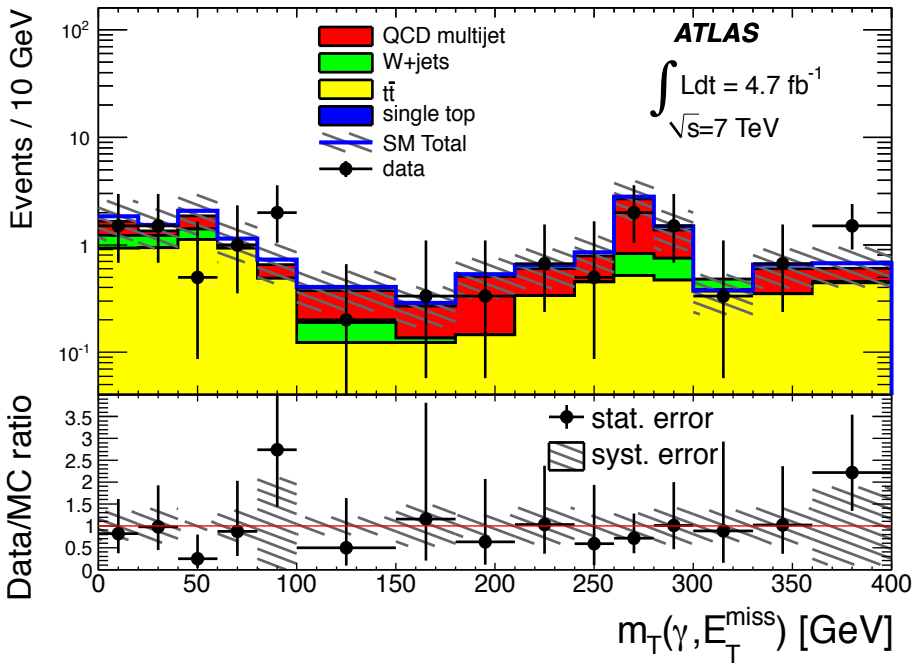
$t\bar{t}$, single top, W+jets

- $W \to e\nu$ w/ $e \to \gamma$ fake
  - electron CR normalized using $e \to \gamma$ fake rate scale factor
- $W \to l\nu$ w/ prompt photon
  - (lepton CR)*(MC transfer factor)

$Z \to \nu\nu$ + γ/jets

- MC

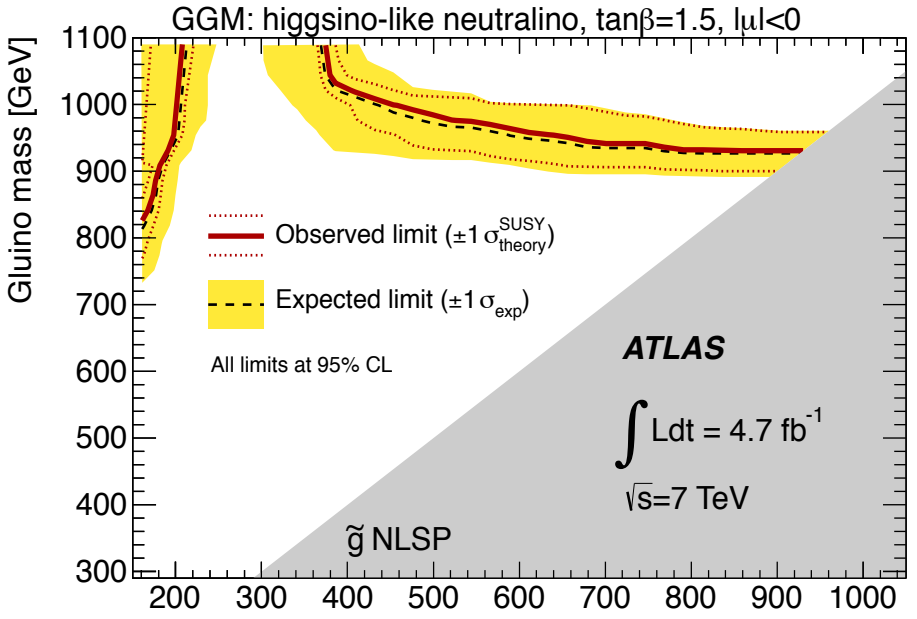


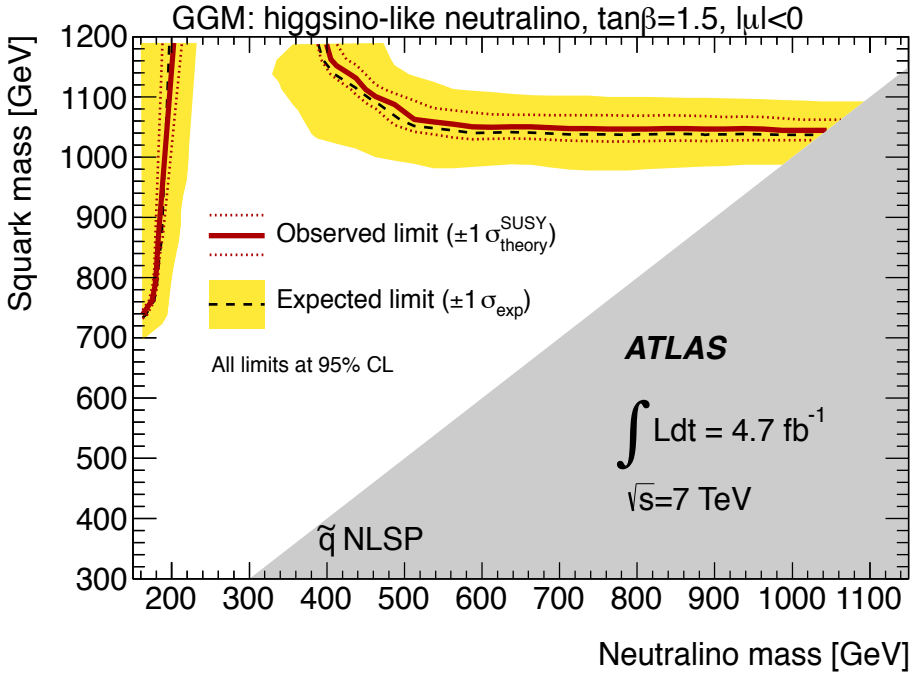


Photon + b-jet + E_T^{Miss}

Phys. Lett. B 719 (2013) 261-279 (4.7 fb-1 @ 7 TeV)

- Expect 7.5 ± 2.2 events
- Observe 7 events
- Set 95% CL limits in GGM planes
  - $\sigma_{vis} < 1.6$ fb
  - $m_{\tilde{g}}$ vs. $m_{\tilde{\chi}_1^0}$
    - Gluino masses below 900 GeV are excluded
  - $m_{\tilde{q}}$ vs. $m_{\tilde{\chi}_1^0}$
    - Squark masses below 1020 GeV are excluded
  - Neutralino masses between 220 GeV and 380 GeV are excluded on the basis of weak production only





Summary

- ATLAS has performed several SUSY searches with photons in the final state
  - Motivated by GMSB/GGM models
- No significant excesses seen over SM predictions
- Exclusion limits set for bino, wino, and higgsino-like NLSPs
  - Prompt bino-like
    - Excluded gluino production with mass < 1280 GeV
    - Excluded wino production with mass < 570 GeV
  - Non-prompt bino-like
    - Probe SPS8 up to Λ = 170 TeV for varying bino lifetimes
  - Wino-like
    - Excluded gluino production with mass < 619 GeV
    - Excluded wino production with mass < 221 GeV
  - Higgsino-bino admixture ($\mu < 0$)
    - Excluded gluino production with mass < 900 GeV
    - Excluded squark production with mass < 1020 GeV
    - Excluded gaugino production with mass between 220 GeV and 380 GeV
- Updates and new channels with 20.3 fb-1 of 8 TeV data coming soon