Searches for supersymmetry in GGM/GMSB scenarios with photons or tau leptons and missing transverse momentum with the ATLAS detector

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21st International Conference on Supersymmetry and Unification of Fundamental Interactions
ICTP Trieste, Italy
26-31 August 2013

Gauge Mediated SUSY Breaking

Intro

- GMSB breaks SUSY via intermediate-scale messenger interactions
  - Naturally protects SM flavor symmetry
  - Gravitino ($\tilde{G}$) is always the LSP :
    - very light and non-interacting → harder spectrum (w.r.t. $\tilde{\chi}_1^0$ LSP case)
  - NLSP can be $\tilde{\chi}_1^0$, $\tilde{\tau}$ or $\tilde{l}_R (\tilde{l} \neq \tilde{\tau})$
    - decays always to $\tilde{G}$ + SM-superpartner
    - Its nature determines the signatures in collider experiments
    - 'free' lifetime → prompt or displaced decay

- Minimal GMSB :
  - Mass spectrum depends on few parameters: $\mathbf{\Lambda, M_{mes}, N_5, \tan(\beta), C_{grav}, sign(\mu)}$
- General Gauge Mediation (GGM) :
  - no specific SUSY mass hierarchy for (un)colored states → any MSSM sp can be NLSP
  - neutralino's nature depends on: **M1, M2, μ, tan(β)**
- Natural Gauge Mediation (nGM) :
  - decouple all sparticles not related to fine-tuning of Higgs sector
  - top squarks and gluinos as only light coloured sparticles

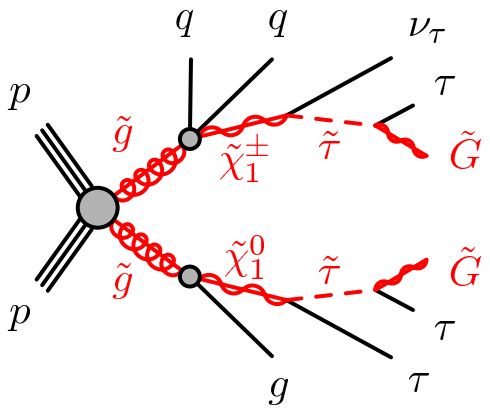
$\tilde{\tau}$

NLSP

1 or ≥ 2 Taus + Jets + MET

ATLAS-CONF-2013-026 (20.7 fb^{-1} @ 8TeV)

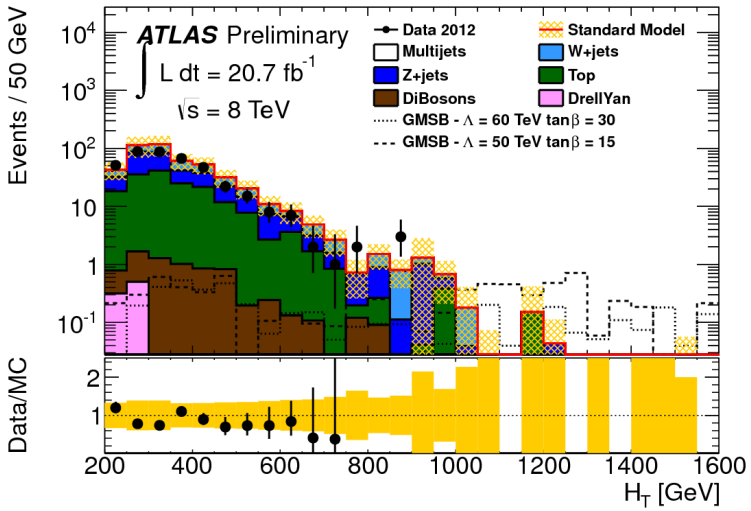
- GMSB $\tilde{\tau}$ NLSP → many taus in final state
- Event selection
  - 1 (≥ 2) τ_h with $p_T^{\tau} > 30(20)$ GeV, no extra light leptons
  - $\not{E}_T > 150\text{GeV}$, $N_{jet} \geq 2$, $p_T^{j1} > 130\text{GeV}$, $p_T^{j2} > 30\text{GeV}$
  - QCD rejection : $\Delta\phi(j_{1,2}, \not{E}_T)$, $\not{E}_T / m_{eff}$ (1τ SR)



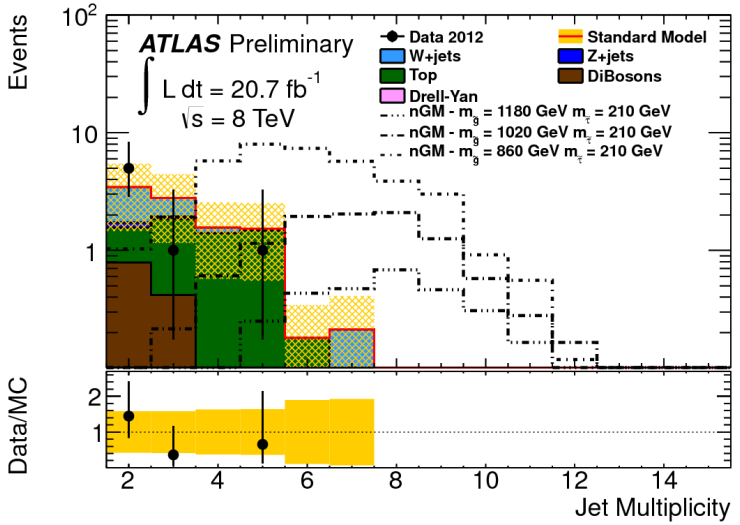
- 3 signal regions:

1τ	2τ GMSB	2τ nGM
$m_T^{\tau} > 140\text{GeV}$	$m_T^{\tau 1} + m_T^{\tau 2} \geq 150\text{GeV}$	$m_T^{\tau 1} + m_T^{\tau 2} \geq 250\text{GeV}$
$H_T \geq 800\text{GeV}$	$H_T \geq 900\text{GeV}$	$H_T \geq 600\text{GeV}$
		$N_{jet} \geq 4$

- Dominant bkg: W/Z+jets, top production 2D CR (m_T vs $n_{b\text{-tags}}$)
  QCD multijets (ABCD τ_{ID} vs $\Delta\phi$) , others (MC)



Final distribution of HT in the 1τ SR



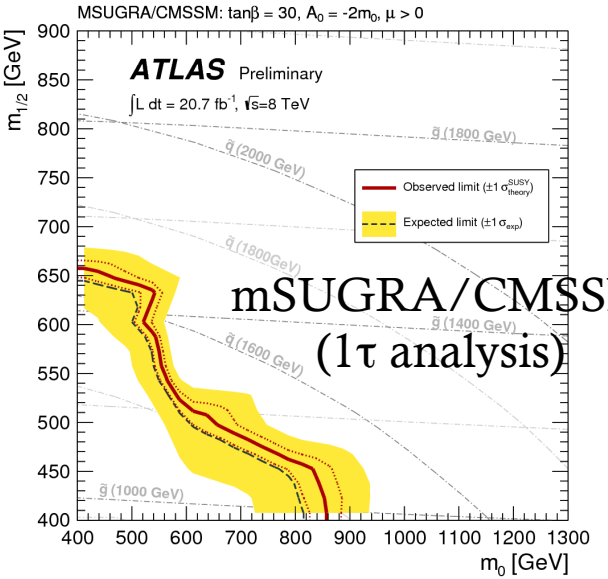
Final distribution of n_{jet} in the 2τ nGM SR

1 or ≥ 2 Taus + Jets + MET

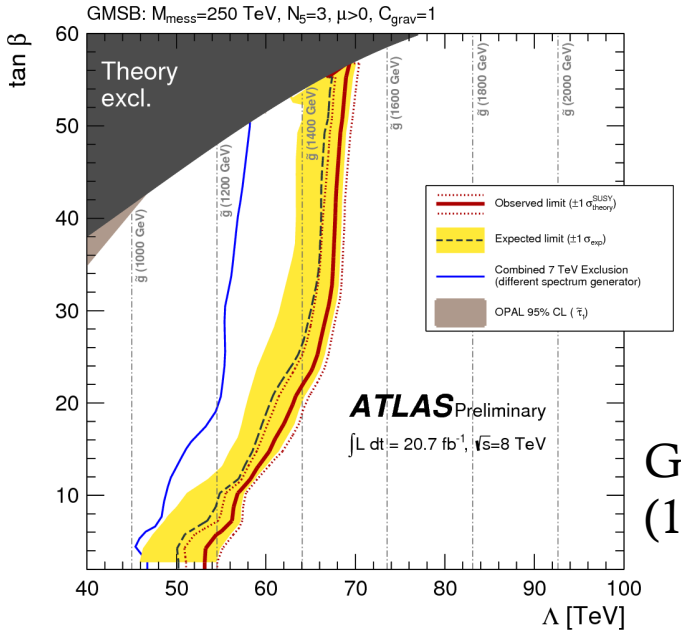
ATLAS-CONF-2013-026 (20.7 fb^{-1} @ 8TeV)

- No excess obs. → 95% CL limits
  (profile likelihood ratio method, CL_s criterion)
- σ_{vis} < 2.4 fb (2τ nGM SR)

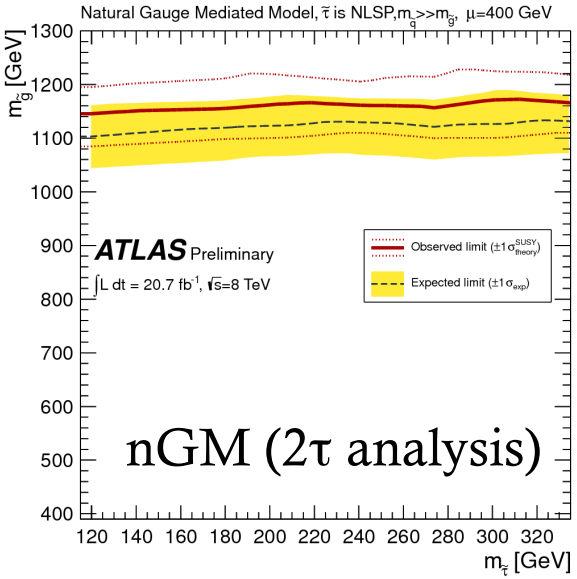
- Interpretation:
  - GMSB : (Λ, tanβ) plane
  - nGM : (m($\tilde{\tau}$), m($\tilde{g}$)) plane
  - mSUGRA/CMSSM : (m_0, $m_{1/2}$) plane



mSUGRA/CMSSM
(1τ analysis)



GMSB
(1τ+2τ combination)

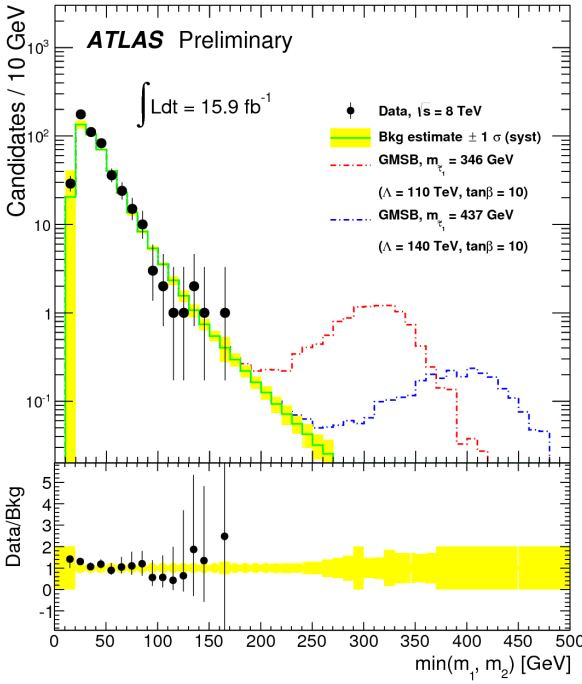


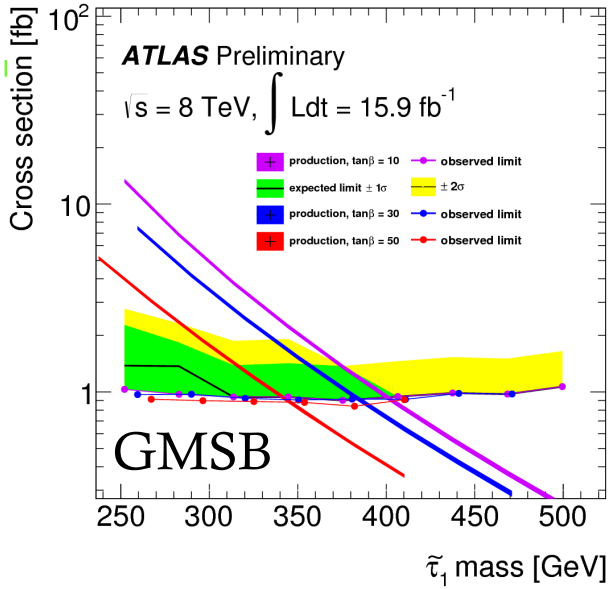
nGM (2τ analysis)

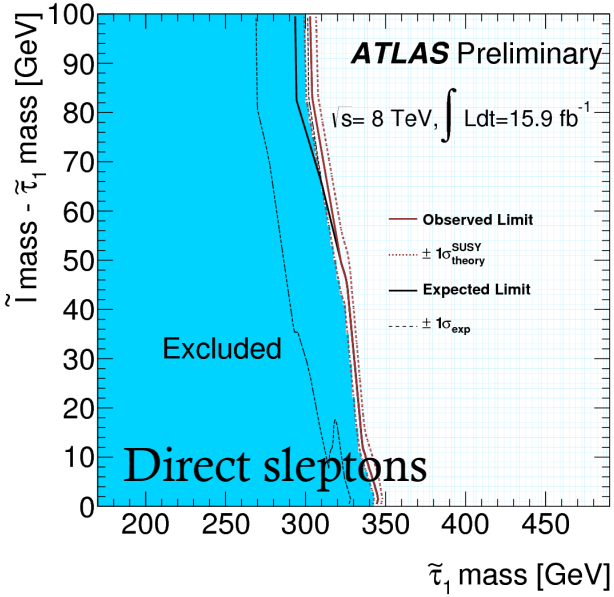
Long-Lived $\tilde{\tau}$

ATLAS-CONF-2013-058 (15.9 fb^{-1} @ 8TeV)

- GMSB $\tilde{\tau}_1$ NLSP, decaying outside the ATLAS volume
- Event selection
  - two loosely identified muons, $p_T > 50$ GeV, $|\eta| < 2.5$,
  - $|m_{\mu\mu} - m_Z| > 10$ GeV
  - β measurement quality criteria
    - consistency among Pixel, Calo & Muon Spectrometer
- Signal selection :
  - Lower Mass cut on two candidates $m = p / \beta\gamma$
- Background : high-p_T muons with mis-measured β (data)







For more on LLP searches in ATLAS see N. Taiblum's talk this Friday

$\tilde{\chi}_1^0$

NLSP

Mix of wino, bino and higgsino

$\left(\tilde{B}^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0\right) \rightarrow \left(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0\right)$

Decay modes

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

- Strongly or weakly produced
- Prompt or long-lived

Bino-like

$\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma$ → γγ+MET (prompt ★, non-prompt ★)

Wino-like (co-NLSP)

$\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma / Z$

$\tilde{\chi}_1^{\pm} \rightarrow \tilde{G} + W^{\pm}$

→ γ+*l*+MET ★

Higgsino-like

Z-rich $\tilde{\chi}_1^0 \rightarrow \tilde{G} + Z$ → Z+MET

h-rich $\tilde{\chi}_1^0 \rightarrow \tilde{G} + h$ → b-jets+MET

γ-rich $\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma$ → γγ+MET

Bino-Higgsino admixture

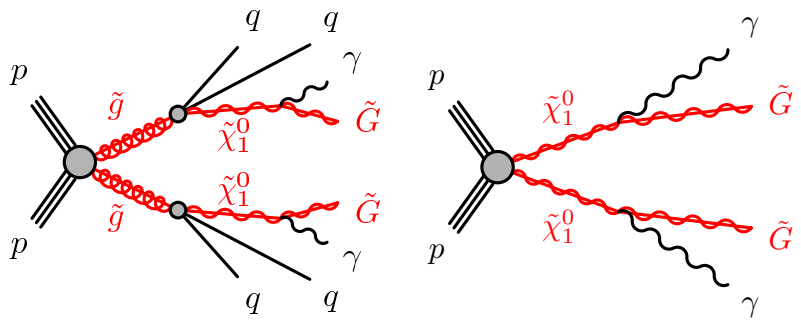
(Low tanβ, μ<0) $\tilde{\chi}_1^0 \rightarrow \tilde{G} + (\gamma, h)$ → γ+b-jets+MET ★

$\tilde{\chi}_1^0 \rightarrow \tilde{G} + (\gamma, Z)$ → γ+jets+MET

γγ+MET (prompt)

Phys. Lett. B 718 (2012) 411-430 (4.8 fb^{-1} @ 7TeV)

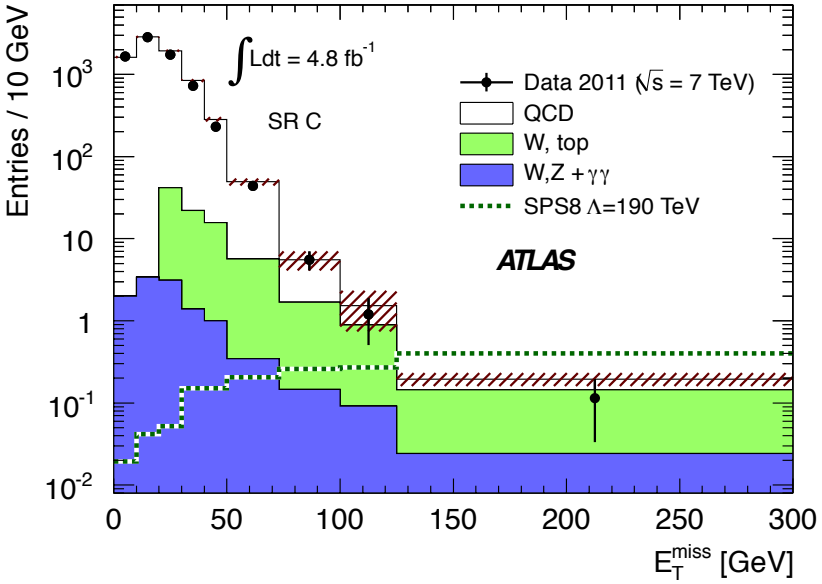
- GGM bino-like NLSP → $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ → γγ and MET in final state
- NLSP decay promptly ($c\tau_{NLSP} < 0.1$ mm)



- Event selection
  - ≥2 γ $p_T > 50$ GeV, Isolation(R = 0.2) < 5 GeV
- Signal regions:

	Strong production		Weak production (SPS8)
	High mass bino	Low mass bino	
	A	**B**	**C**
$\Delta\phi(\gamma, \not{E}_T) >$	0.5	-	0.5
$H_T >$	600 GeV	1100 GeV	-
$\not{E}_T >$	200 GeV	100 GeV	125 GeV

- Dominant bkg:
  - QCD multi-jet, γ+jet (CR * low-MET scale factor)
    - (cross-checked HT-bins extrapolation)
  - EWK W+X, ttbar (lepton CR * e→γ factor from data)
  - Irreducible Z(νν)γγ, W(eν)γγ (MC)



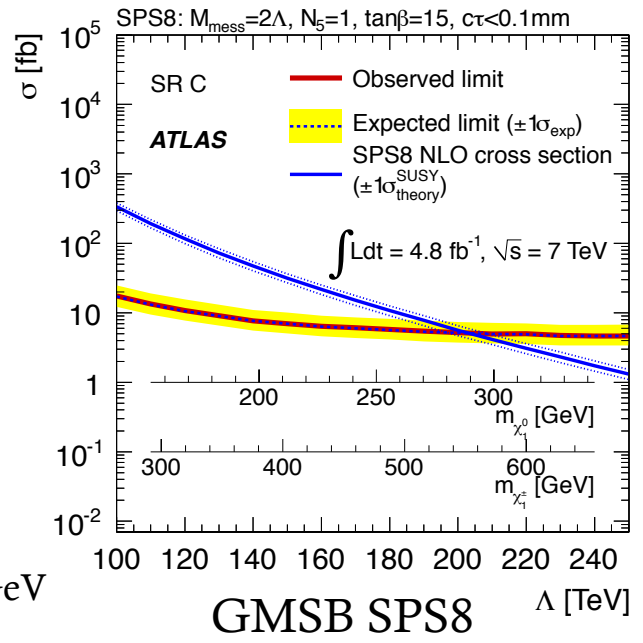
γγ+MET (prompt)

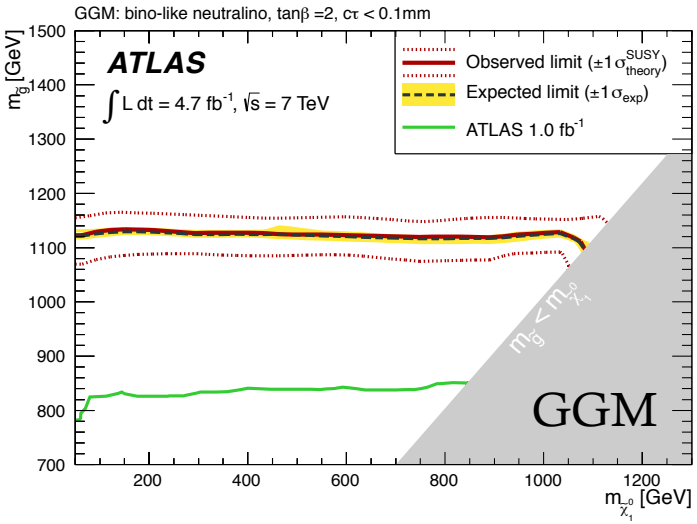
Phys. Lett. B 718 (2012) 411-430 (4.8 fb^{-1} @ 7TeV)

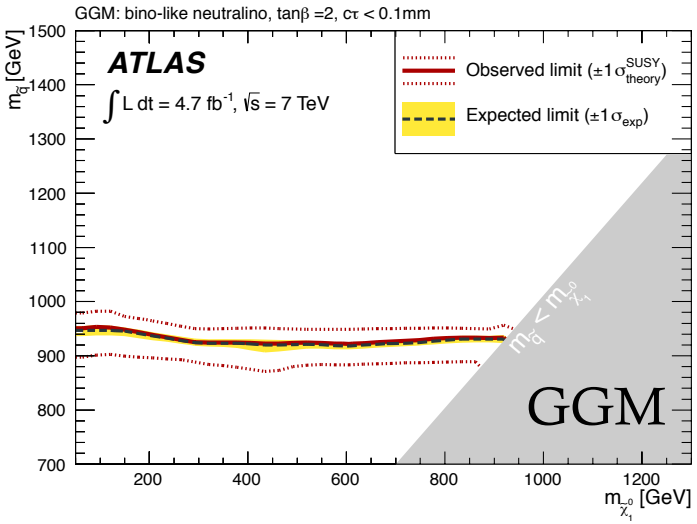
- No excess obs. → 95% CL limits
  (profile likelihood ratio method, CL_s criterion)
- $\sigma_{vis} < 0.6$ fb (SR A)
- $\sigma_{vis} < 0.6$ fb (SR B)
- $\sigma_{vis} < 1.0$ fb (SR C)

- Interpretation:
  - GMSB : Λ → $\Lambda > 196$ TeV
  - GGM : $(m(\tilde{\chi}_1^0), m(\tilde{g}))$ → $m(\tilde{g}) > 0.87$ TeV
  - GGM : $(m(\tilde{\chi}_1^0), m(\tilde{q}))$ → $m(\tilde{q}) > 1.07$ TeV

$m(\tilde{\chi}_1^0)$>50GeV



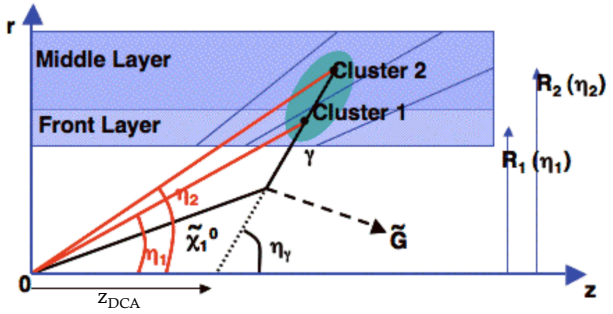




γγ+MET (non-prompt)

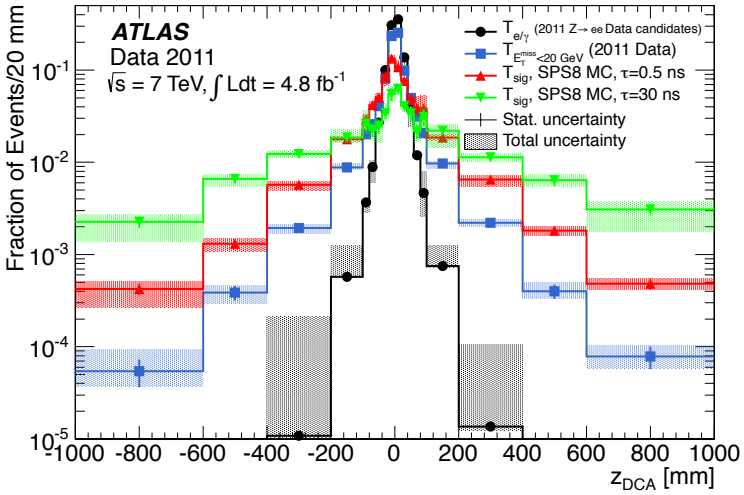
Phys. Rev. D 88, 012001 (2013) (4.8 fb^{-1} @ 7TeV)

- GMSB bino-like NLSP + finite $\tilde{\chi}_1^0$ lifetime → 2 non-pointing γ + MET in final state
- Exploits excellent pointing and timing capabilities of ATLAS EM calorimeter
- Event selection
  - 2 photons with $p_T^\gamma > 50$GeV, Isolation(R = 0.2) < 5 GeV
  - 'TL' ID : 1 tight γ (|η| < 2.37) + 1 loose γ (|η| < 1.37)
  - $\not{E}_T > 75$ GeV

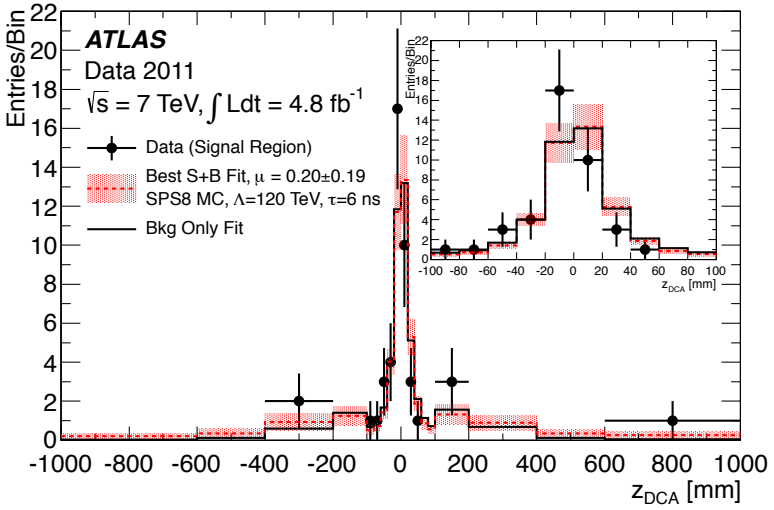


- Fit z_{DCA} distribution to S+B model
  - Cross-checked with photon arrival time distribution.

- Dominant bkg: prompt γ/misId-electron (Z_{ee} data), misId-jet (low MET TL data)



z_{DCA} templates for signal and background.



z_{DCA} for data in SR.

γγ+MET (non-prompt)

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

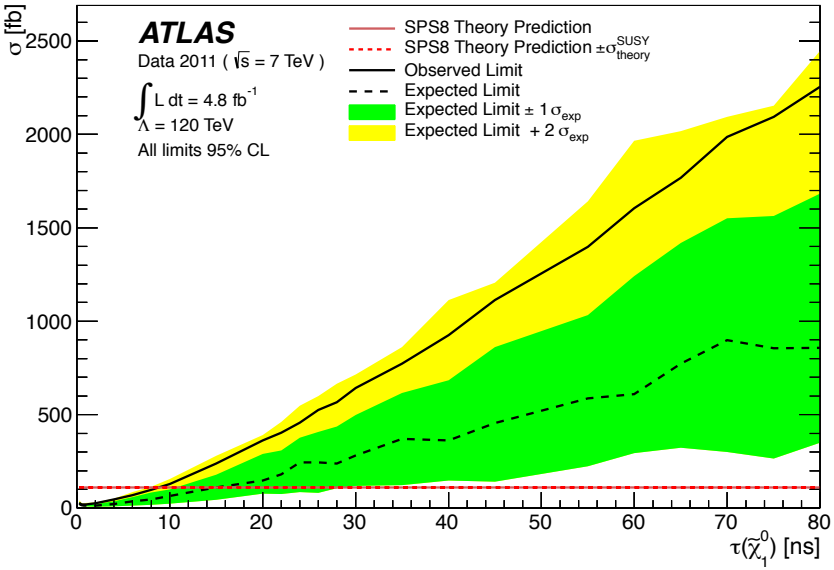
- No excess obs. → 95% CL limits (CL_s criterion)
- Interpretation:
  - GMSB SPS8 :

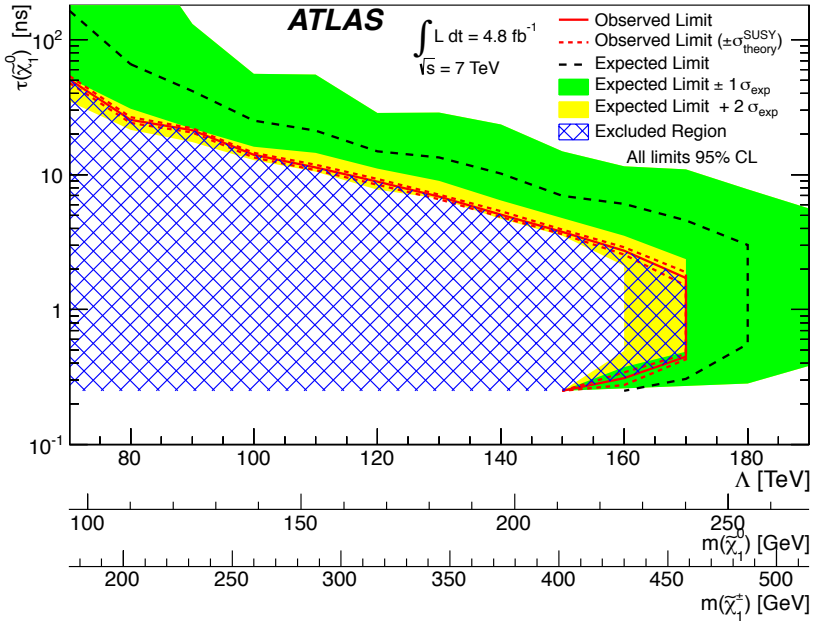
$\tau(\tilde{\chi}_1^0)$ vs Λ

$\tau(\tilde{\chi}_1^0)$ vs $m(\tilde{\chi}_1^0)$

$\tau(\tilde{\chi}_1^0)$ vs $m(\tilde{\chi}_1^\pm)$

    - Λ = 120 TeV
      - Obs. Limit : **$\tau > 8.7$ ns**
      - Exp. Limit : $\tau > 14.6$ ns
    - Λ = 70 TeV
      - **$0.25 < \tau < 50.7$ ns excluded 95% CL**
    - Λ = 160 TeV
      - **$0.25 < \tau < 2.7$ ns excluded 95% CL**





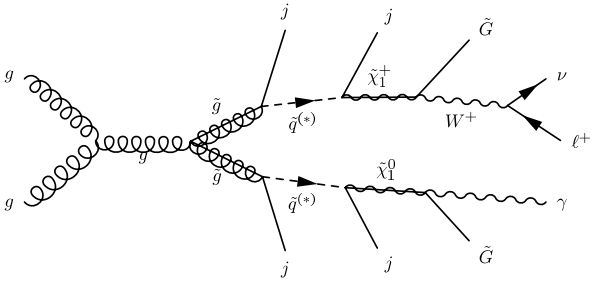
See N. Taiblum's talk this Friday

γ+lepton+MET

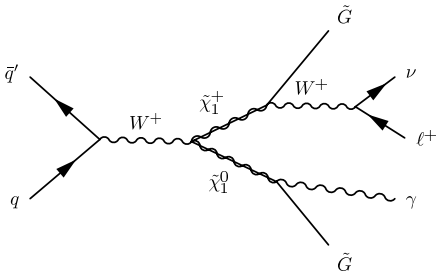
ATLAS-CONF-2012-144 (4.8 fb^{-1} @ 7TeV)

- GGM wino-like NLSP
- $m(\tilde{\chi}_1^0) \sim m(\tilde{\chi}_1^\pm)$ → $\tilde{\chi}_1^0 \to \tilde{G}(Z,\gamma)$ → γ, *l* and MET in final state

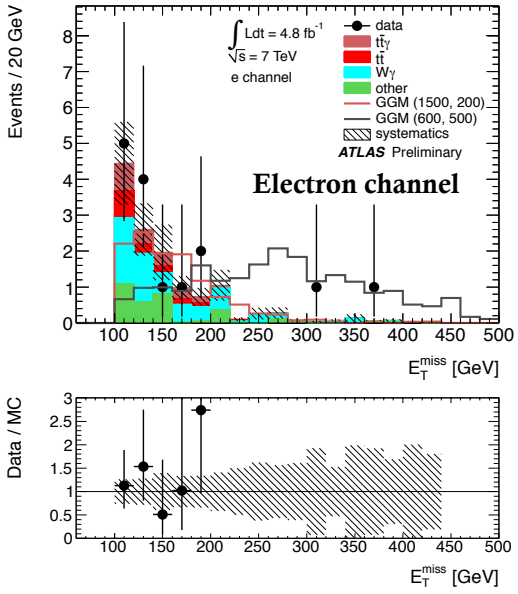
$\tilde{\chi}_1^\pm \to \tilde{G}W^\pm$



Strong production

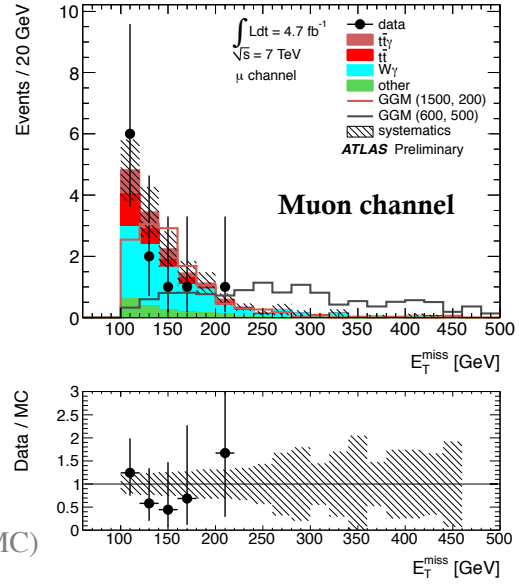


Weak production



- Event selection

Electron channel	Muon channel
≥ 1 γ , p_T > 100 GeV	≥ 1 γ , p_T > 85 GeV
≥ 1 e , p_T > 25 GeV	≥ 1 μ , p_T > 25 GeV
no μ , p_T > 25 GeV	No e , p_T > 25 GeV
$\lvert m_{e\gamma} - m_z \rvert$ > 15 GeV	
$\Delta R(l,\gamma)$ > 0.7	$\Delta R(l,\gamma)$ > 0.7

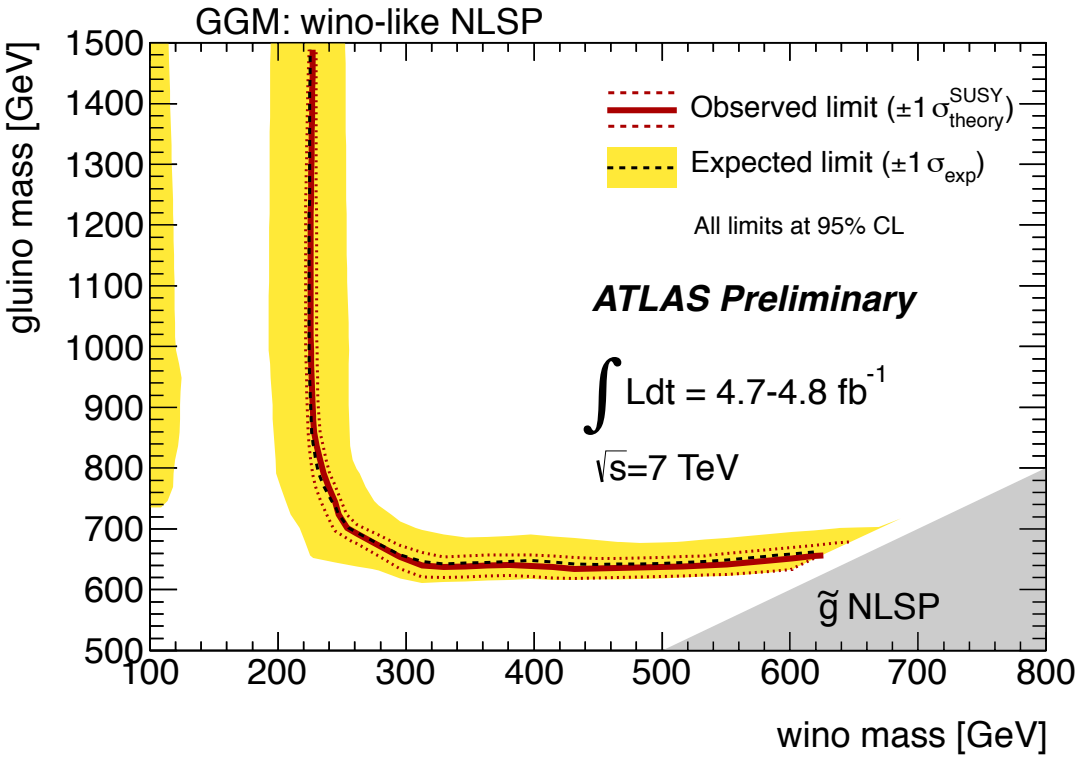


- Signal region: $\not{E}_T > 100\text{GeV}$, $m_T(l, \not{E}_T) > 100\text{GeV}$
- Dominant bkg: Wγ, tt̄γ, (fully-lep)tt̄ MC (validated vs data)
  W+jets, (semi-lep)tt̄ (ABCD γ-ID vs γ-iso), γ+jet (matrix method), others (MC)

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

- No excess obs. → 95% CL limits
  (profile likelihood ratio method, CL_s criterion)

- e-channel : $\sigma_{vis} < 2.7$ fb
- μ-channel : $\sigma_{vis} < 1.8$ fb



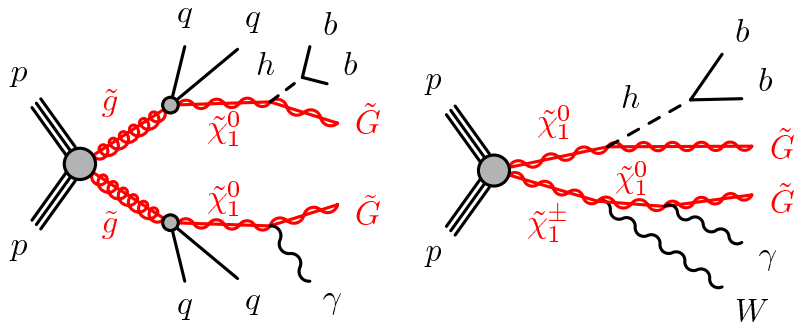
- Interpretation:
  - GGM wino-like NLSP
  - Combined electron+muon channels for model-dependent limits

  - **Gluino mass > 619 GeV for any wino mass (below $m(\tilde{g})$).**
  - **Wino mass > 221 GeV for any gluino mass.**

γ+b+MET

Phys. Lett. B 719 (2013) 261-279 (4.8 fb^{-1} @ 7TeV)

- GGM bino-higgsino admixture NLSP
- $\mu < 0,\ M1 \sim -\mu \rightarrow \begin{matrix} \tilde{\chi}_1^0 \rightarrow \tilde{G}(h,\gamma) \\ h \rightarrow b\bar{b} \end{matrix}$ → γ, bjets and MET in final state



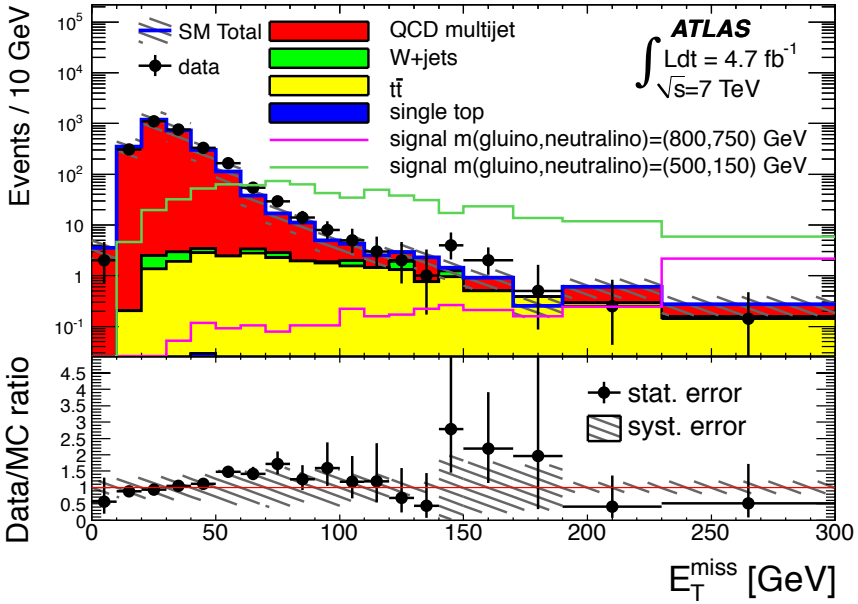
- Event selection
  - 1γ $p_T > 125$ GeV
    - No 2nd γ $p_T > 50$ GeV
  - ≥ 2 jets $p_T > 20$ GeV , ≥ 1 b-tagged
  - Lepton veto
  - $\Delta\phi(j_{1,2}, \not{E}_T) > 0.4$
- Signal region:

  $\not{E}_T > 150$ GeV, $m_T(\gamma, \not{E}_T) > 100$ GeV
- Dominant bkg:

  ttbar, ttbarγ, W+jets
  - W(lν)+e (lepton CR * e→γ factor from data)
  - W(lν)+γ/jet(→γ) (γ+lepton CR * MC scale)

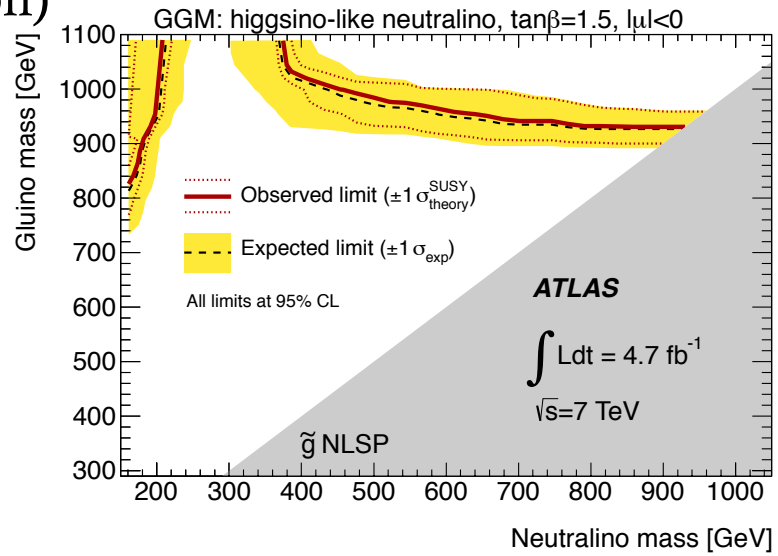
  Multijets (ABCD Etmiss vs N_{tags})

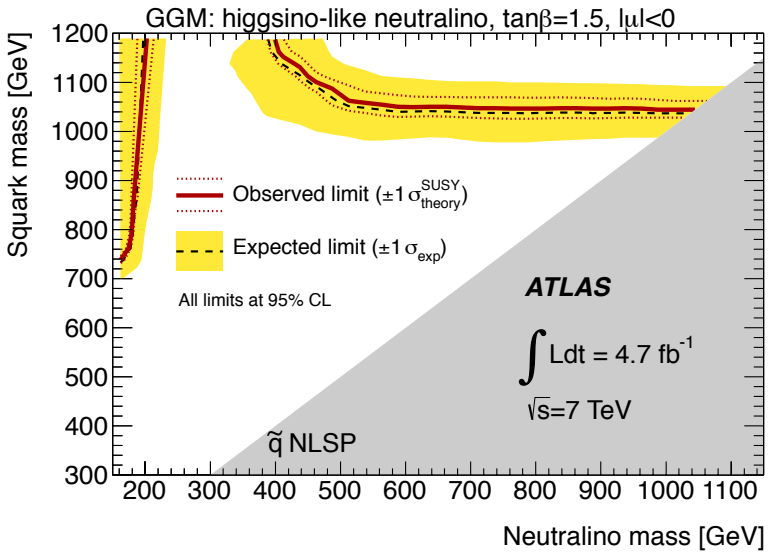
  Others ($Z(\rightarrow \nu\bar{\nu})$+jets) (MC)



Phys. Lett. B 719 (2013) 261-279 (4.8 fb^{-1} @ 7TeV)

- No excess obs. → 95% CL limits
  (profile likelihood ratio method, CL_s criterion)
- $\sigma_{vis} < 1.6$ fb
- Interpretation:
  - GGM bino-higgsino NLSP
  - Combined strong and weak production limits
  - For $m(\tilde{\chi}_1^0) > 220$ GeV
    - **Gluino mass > 900 GeV**
    - **Squark masses > 1020 GeV**
  - $220\ \text{GeV} < m(\tilde{\chi}_1^0) < 380\ \text{GeV}$ **excluded regardless gluino or squark masses!**
    (on the basis of the expected weak production)





More on GMSB/GGM…

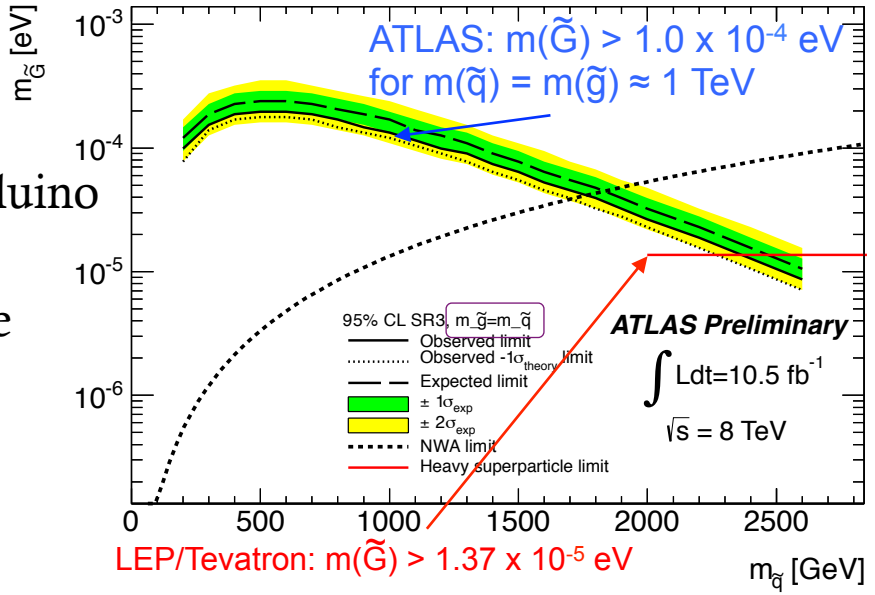
Monojet+MET

ATLAS-CONF-2012-147 (10.5 fb^{-1} @ 8TeV)

- Associated production of gravitino + squark/gluino
- $\sigma \sim 1/m_{\tilde{G}}$ → constrain $m_{\tilde{G}}$!
- Gravitino mass probes the SUSY-breaking scale

$$m_{\tilde{G}} \propto F / M_{pl}$$

See B. Oexl's talk yesterday

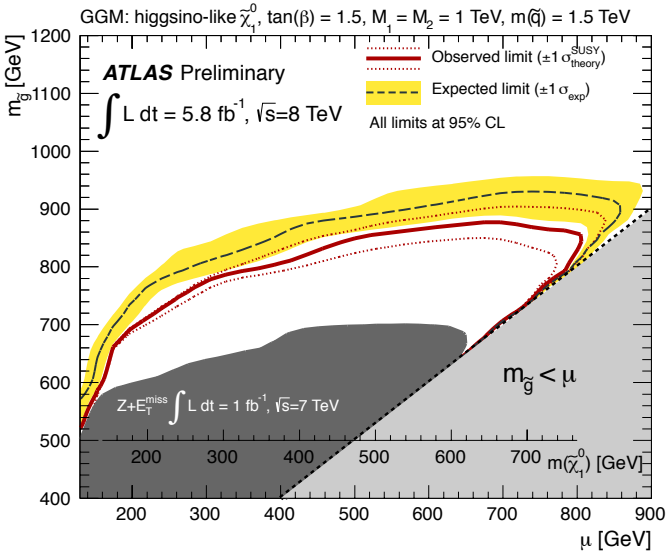


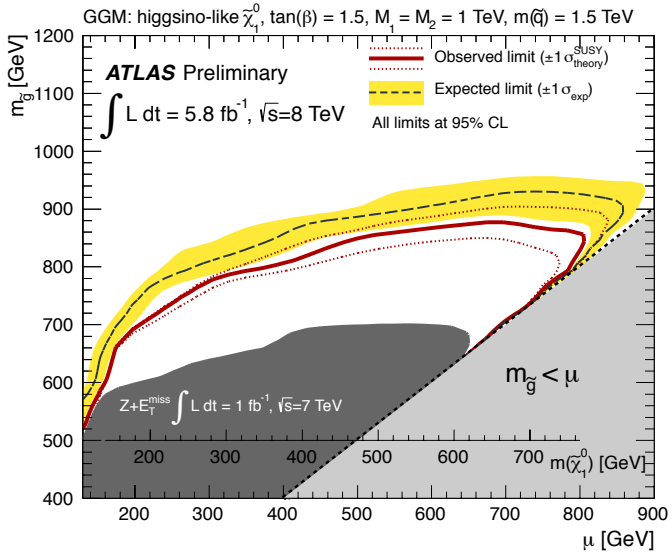
Z+jets+MET

ATLAS-CONF-2012-152

(5.8 fb^{-1} @ 8TeV)

Higgsino-like $\tilde{\chi}_1^0$ NLSP





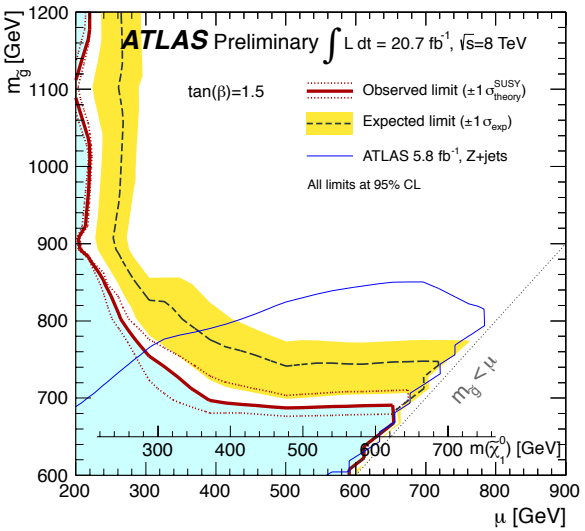
More on GMSB/GGM…

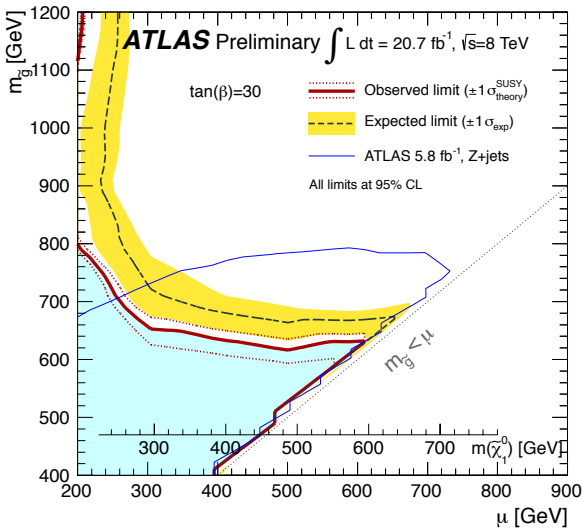
4leptons+MET

ATLAS-CONF-2013-036
(20.7 fb^{-1} @ 8TeV)

Higgsino-like $\tilde{\chi}_1^0$ NLSP

See T. Potter's talk this Thursday



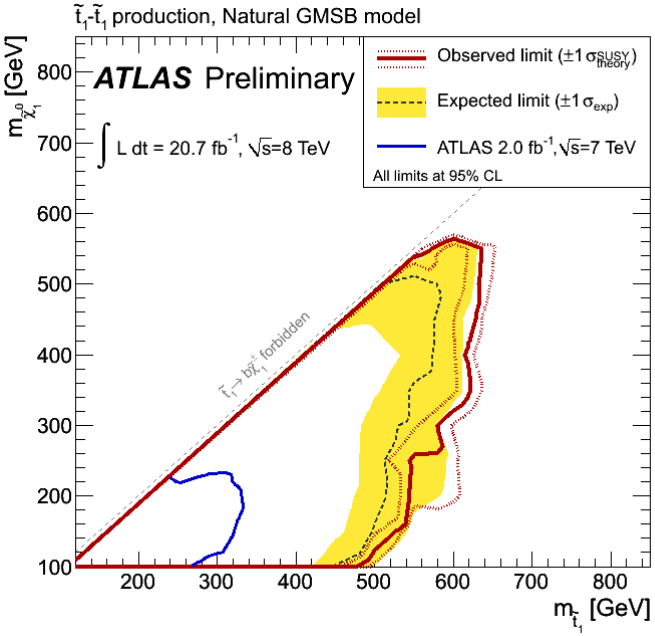


Z+b-jets+MET

ATLAS-CONF-2013-025
(20.7 fb^{-1} @ 8TeV)

Direct scalar top pair production
Higgsino-like $\tilde{\chi}_1^0$ NLSP

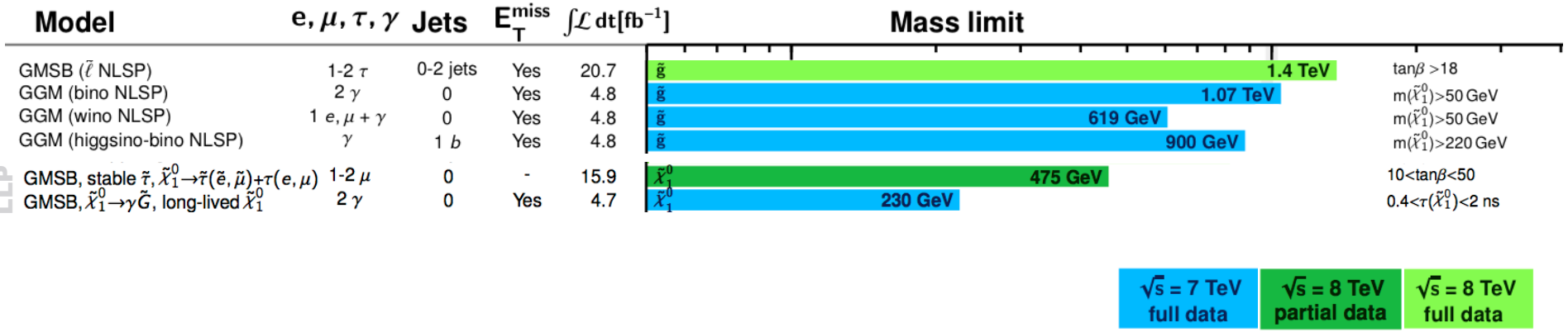
See P. Jackson's talk this Thursday



Summary

- Presented several SUSY searches with photons or taus in ATLAS
  - Covering all signatures predicted by GMSB phenomenology.

- No significant excesses observed over SM predictions
  - 95% CL upper limits placed on visible cross sections
  - Stringent constraints in GMSB/GGM/nGM parameters



- Ongoing updates with full 2012 8TeV datasets
  - expected to improve sensitivity in all channels
  - new channels and benchmark models already in the loop