Current status of GMSB searches at ATLAS

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on behalf of the ATLAS collaboration

SUSY at the Near Energy Frontier
Fermilab

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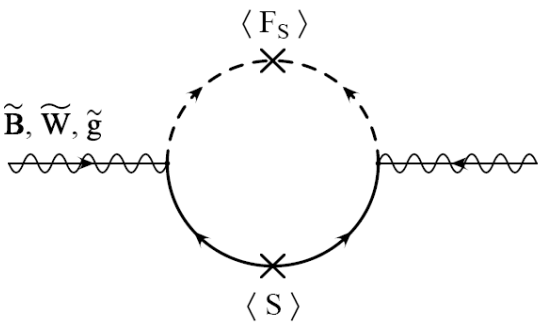
https://indico.fnal.gov/conferenceTimeTable.py?confId=7321#all.detailed

NEW YORK UNIVERSITY

ATLAS

Introduction

- Gauge-Mediated SUSY Breaking (GMSB)
- Gravitino is the LSP
- NLSP is generally χ_1^0, or stau, or other slepton
  - Decays to gravitino (MET) + SM partner
  - Can be long-lived → prompt or displaced decay or escape detector



Bino-like

$\tilde{\chi}_1^0 \to \tilde{G} + \gamma$ → γγ+MET prompt ★ non-prompt ★

Wino-like (co-NLSP)

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

$\tilde{\chi}_1^{\pm} \to \tilde{G} + W^{\pm}$ → γ+*l*+MET ★

Higgsino-like

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

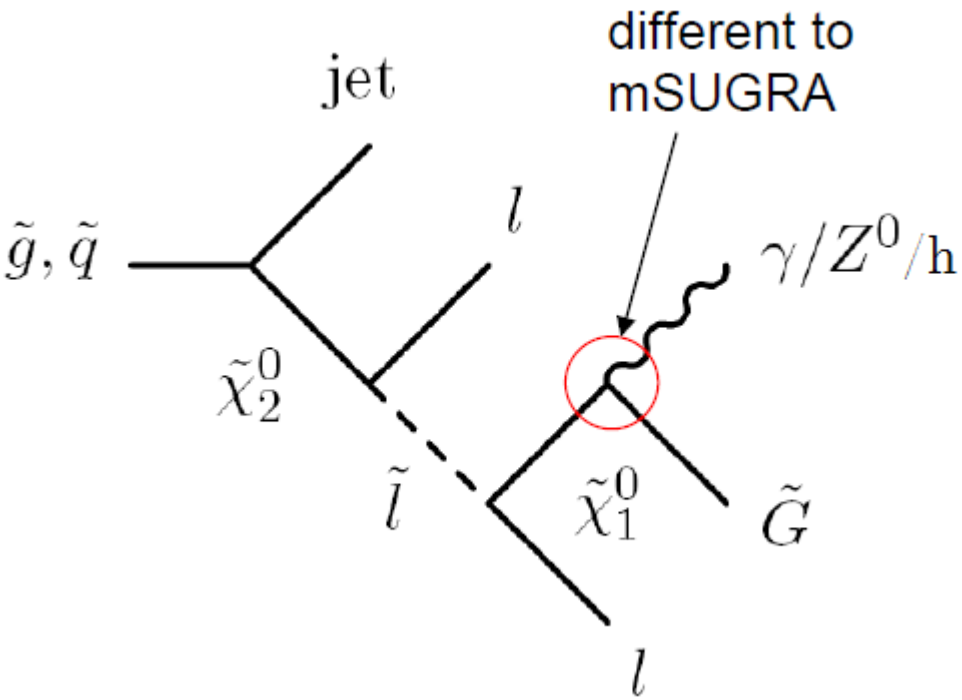
h-rich $\tilde{\chi}_1^0 \to \tilde{G} + h$ → b-jets+MET

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

Bino-Higgsino admixture

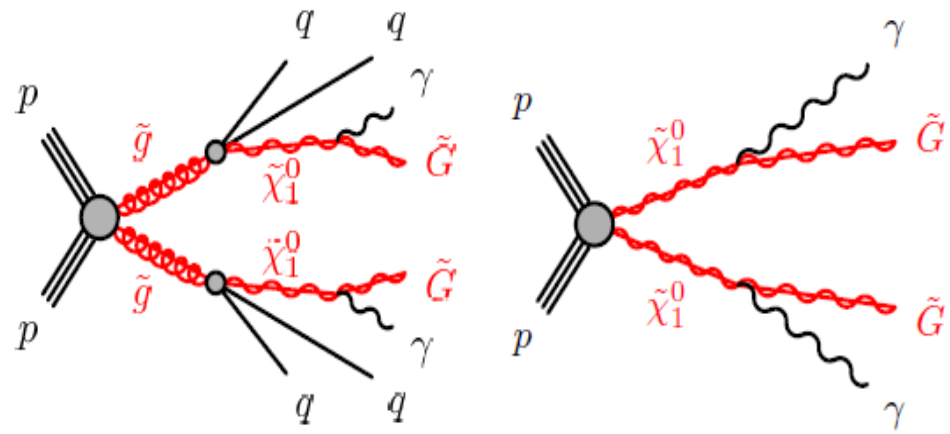
(Low tanβ, μ<0) $\tilde{\chi}_1^0 \to \tilde{G} + (\gamma, h)$ → γ+b-jets+MET ★

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



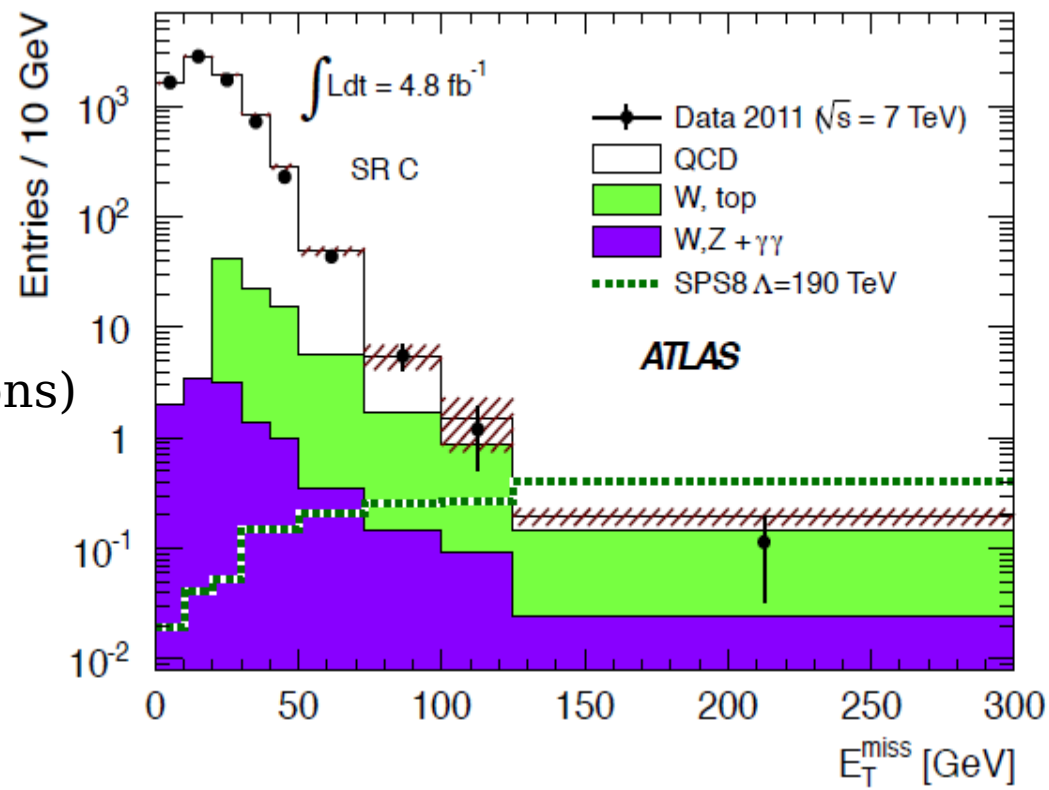
Prompt di-photon + MET

- At least 2 photons (ctau<0.1mm)
  - pT > 50 GeV
  - Isolated (<5 GeV in dR<0.2)



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



QCD:
Data-driven (low-MET,HT control regions)

W+jets / ttbar:
Data-driven e → γ fake rate

Irreducible (W/Z + γγ):
MC – known to NLO

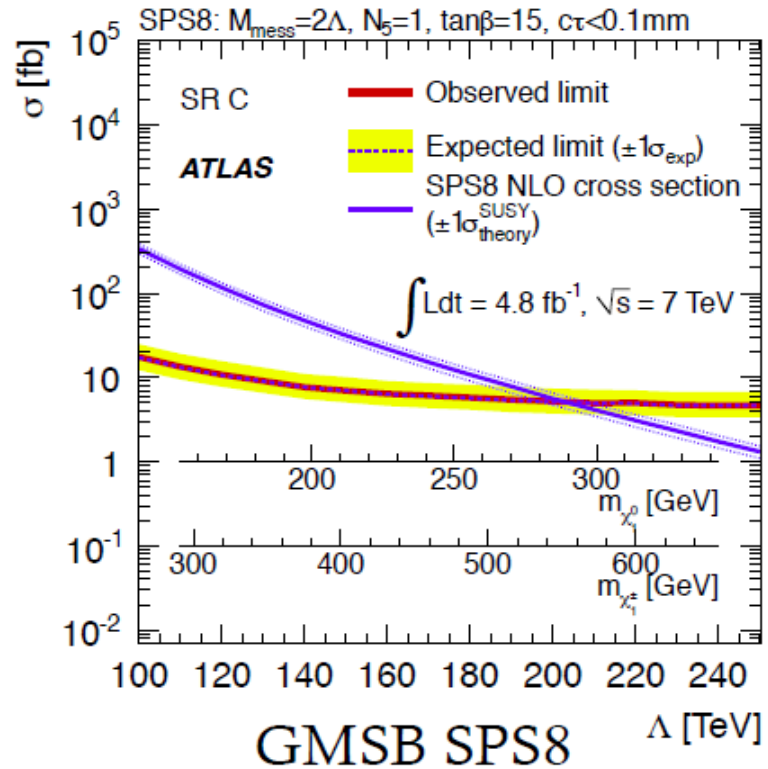
Phys. Lett. B 718 (2012) 411-430.

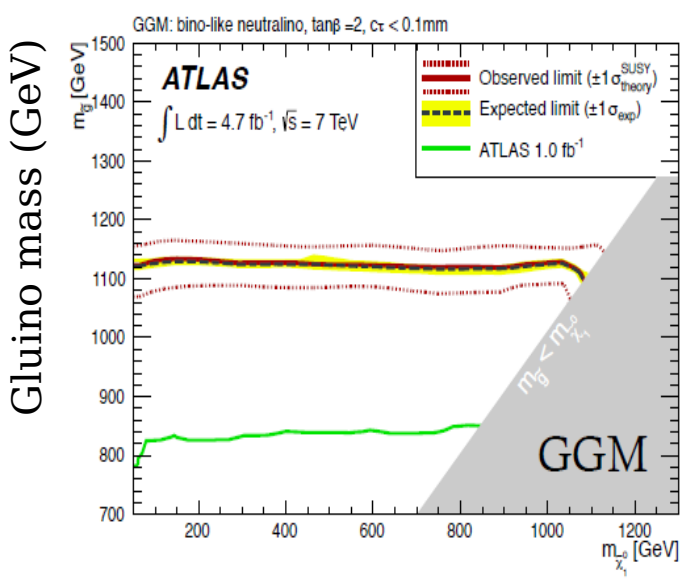
Prompt di-photon + MET

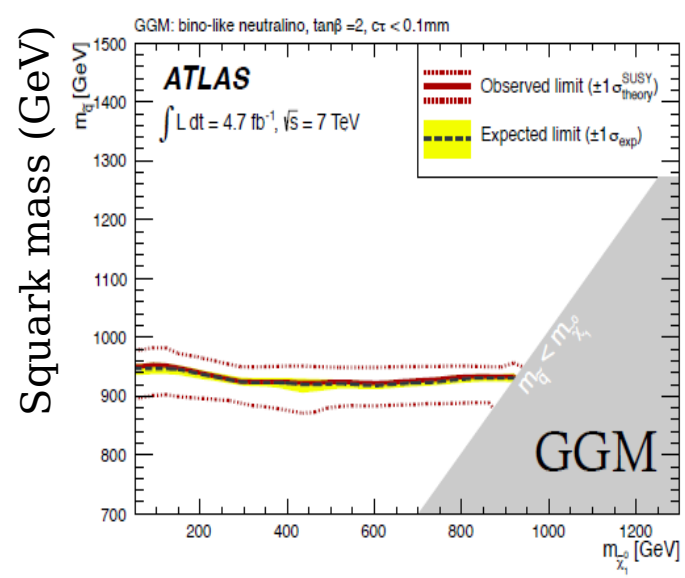
No excess obs. → 95% CL limits
(profile likelihood ratio method, CL_s criterion)

$\sigma_{vis} < 0.6$ fb (SR A)
$\sigma_{vis} < 0.6$ fb (SR B)
$\sigma_{vis} < 1.0$ fb (SR C)

- GMSB: Λ>196 TeV
- GGM: gluino > 1.07 TeV
  squark > 0.87 TeV (for $m(\chi_1^0)$>50 GeV)



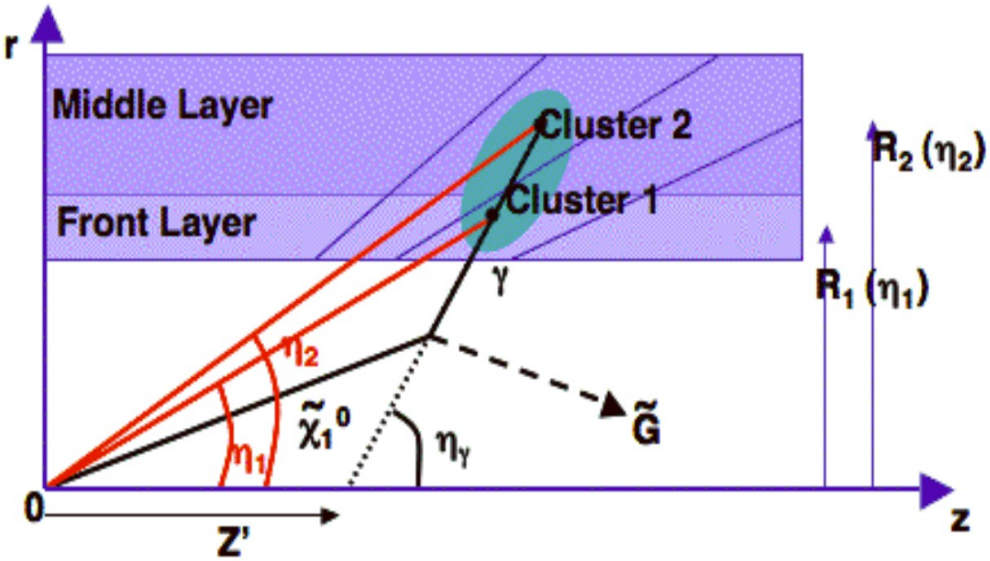




Non-prompt di-photon + MET

- At least 2 photons
  - pT > 50 GeV
  - Isolated (<5 GeV in dR<0.2)

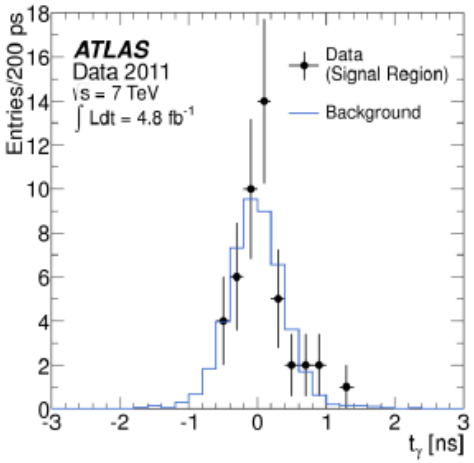
Longitudinal segmentation!

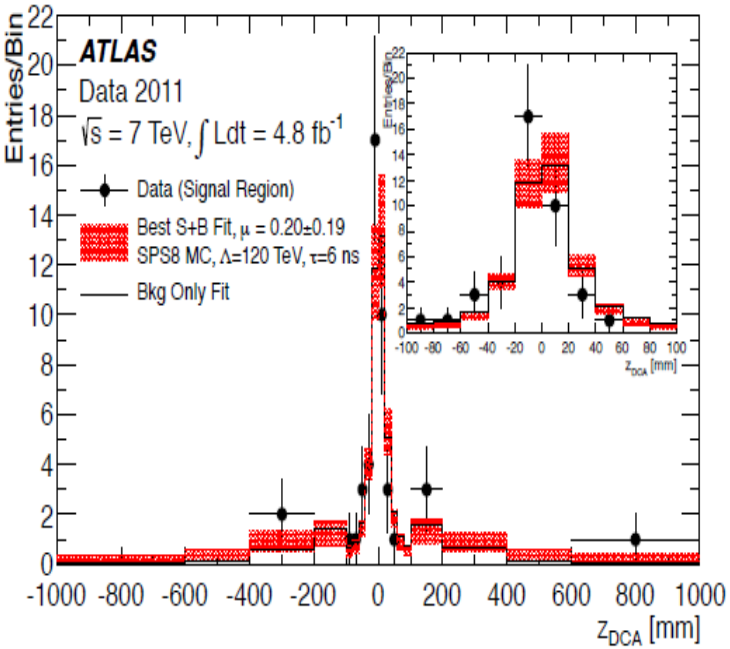


- Use *timing* and *shower direction* to distinguish photons from displaced decay

- Allow one photon to have "loose" photon shower shape in calorimeter to increase efficiency for non-pointing photons in signal (in |eta|<1.37)

- MET > 75 GeV





Phys. Rev. D 88, 012001 (2013).

Non-prompt di-photon + MET

No excess obs. → 95% CL limits
(CL_s criterion)

Interpretation:

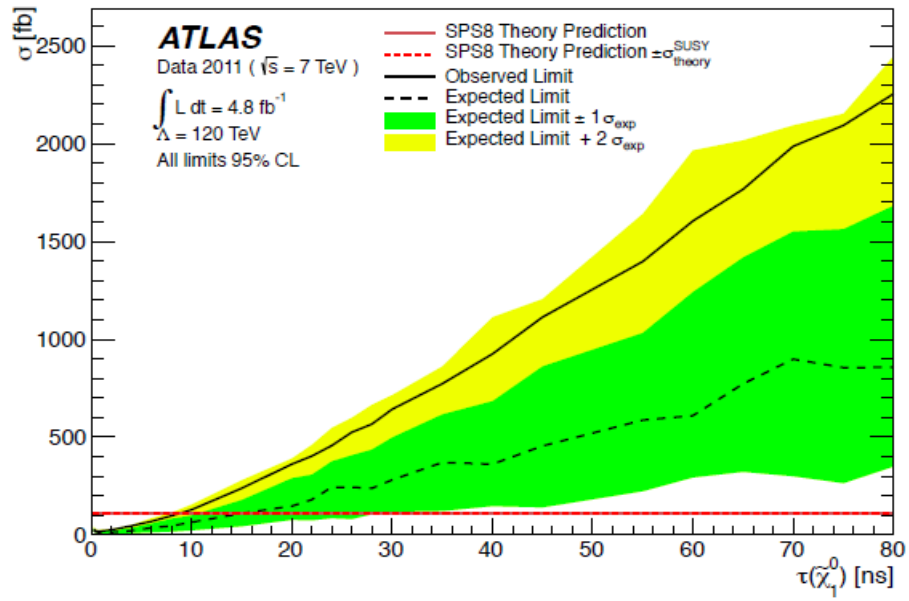
- GMSB SPS8 :

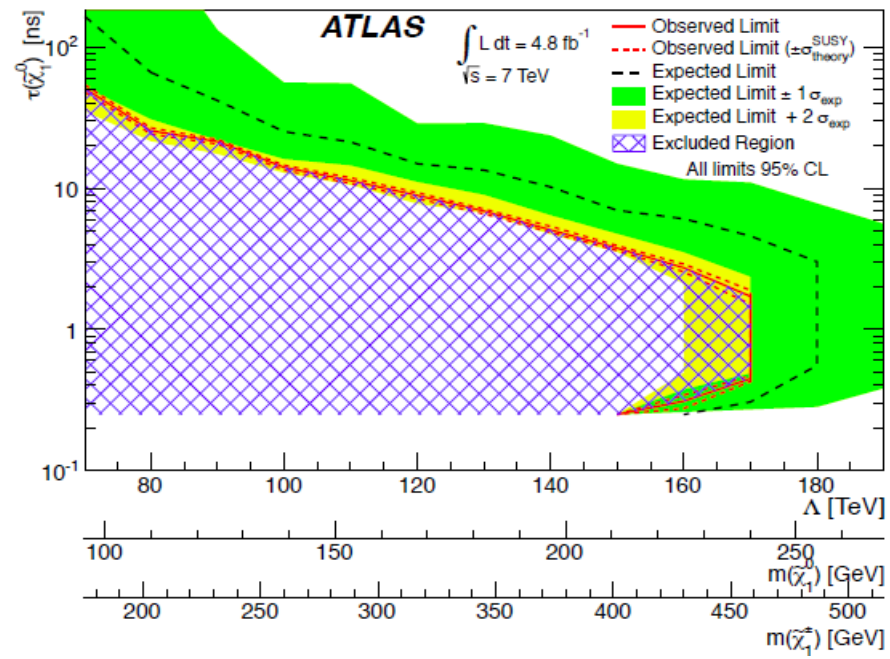
$\tau(\tilde{\chi}_1^0)$ vs Λ

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

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

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



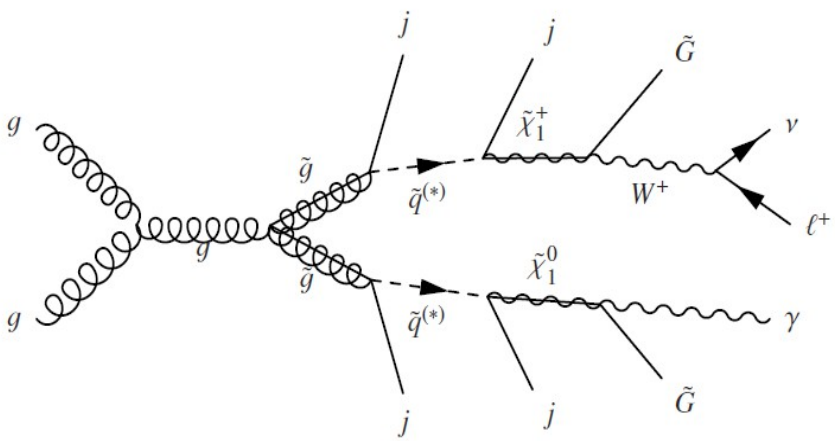


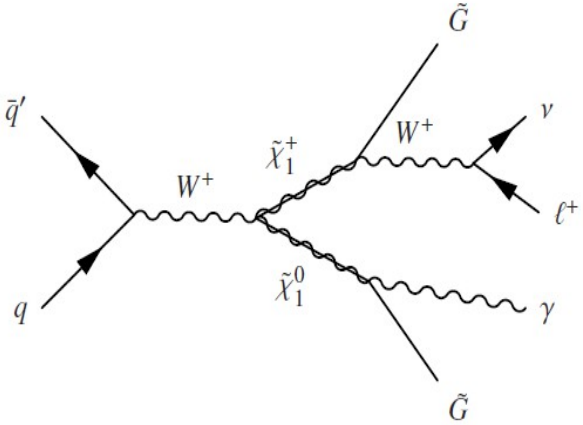
Updating with 8 TeV data and improved calibrations and techniques!

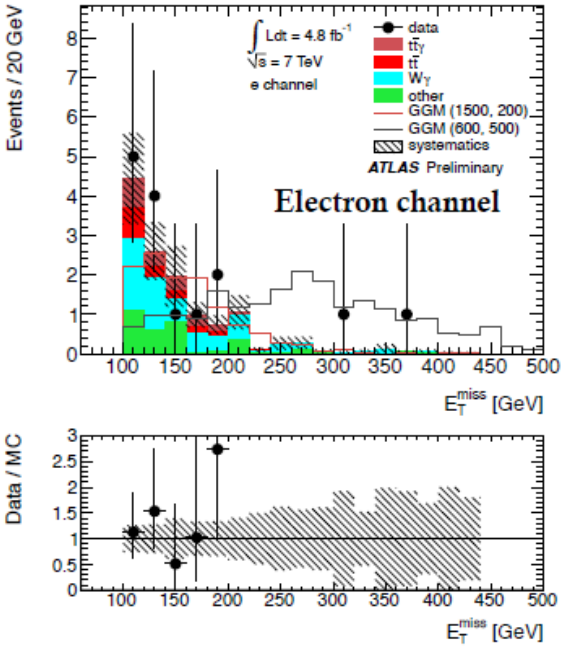
Photon+lepton+MET

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

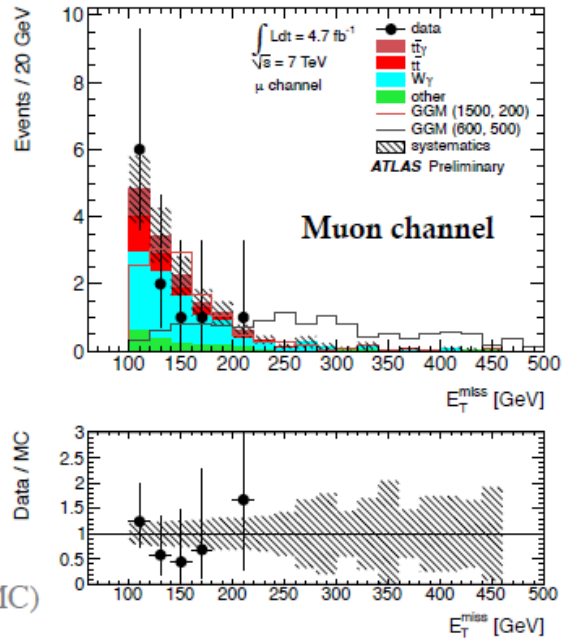
  $\tilde{\chi}_1^\pm \rightarrow \tilde{G}W^\pm$







Electron channel	Muon channel
$\geq 1\ \gamma$, $p_T > 100$ GeV	$\geq 1\ \gamma$, $p_T > 85$ GeV
≥ 1 e , $p_T > 25$ GeV	$\geq 1\ \mu$, $p_T > 25$ 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: $W\gamma$, $t\bar{t}\gamma$, (fully-lep)$t\bar{t}$ MC (validated vs data)

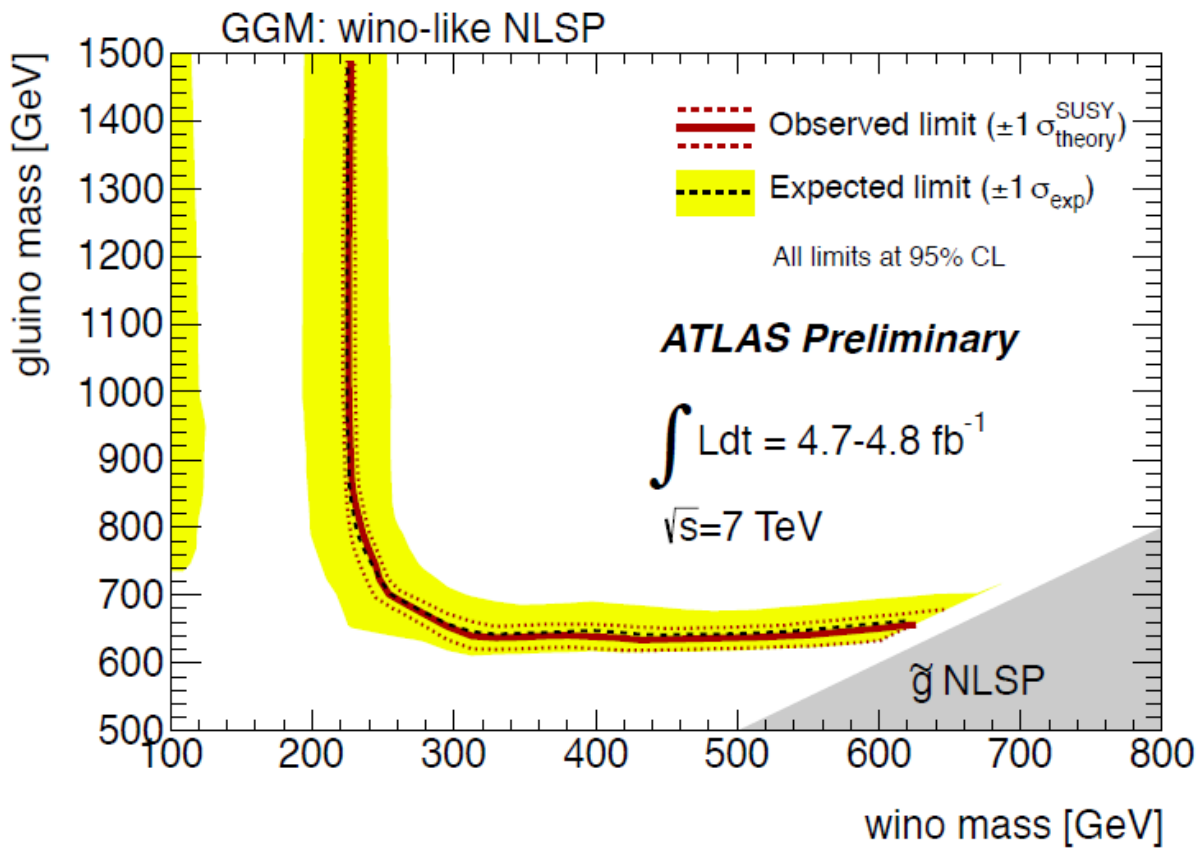
  W+jets, (semi-lep)$t\bar{t}$ (ABCD γ-ID vs γ-iso), γ+jet (matrix method), others (MC)

Photon+lepton+MET

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

ATLAS-CONF-2012-144

- 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

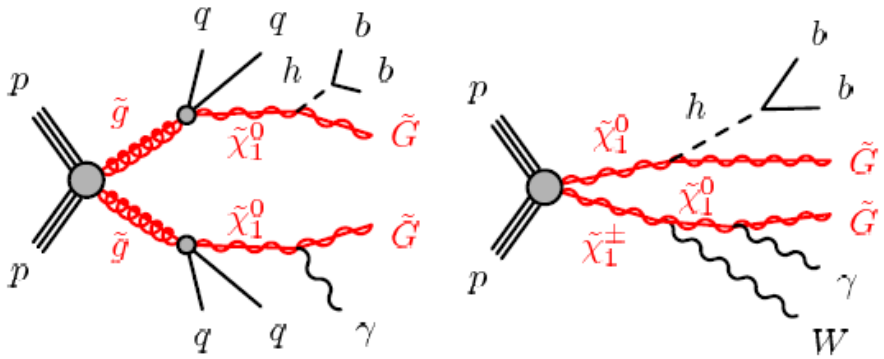
  - **Gluino mass > 619 GeV for any wino mass (below $m(\tilde{g})$).**
  - **Wino mass > 221 GeV for any gluino mass.**

Photon + b-jet + MET

- GGM bino-higgsino admixture NLSP

Phys. Lett. B 719 (2013) 261-279.

- $\mu < 0,\ M1 \sim -\mu \rightarrow \begin{array}{l} \tilde{\chi}_1^0 \rightarrow \tilde{G}(h,\gamma) \\ h \rightarrow b\bar{b} \end{array}$ → 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:

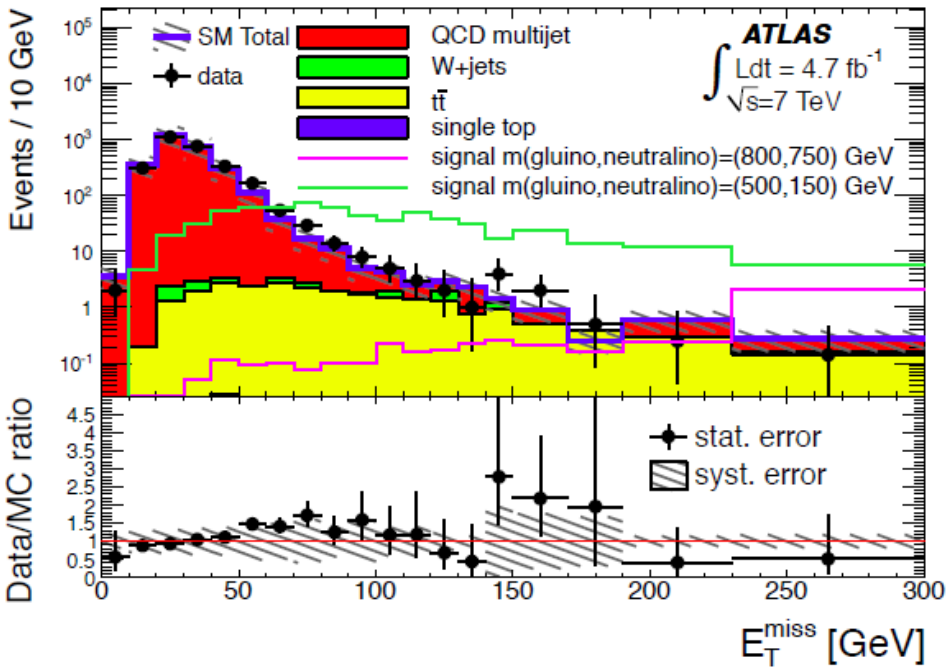
  $\not{E}_T > 150$ GeV, $m_T(\gamma, \not{E}_T) > 100$ GeV

- Dominant bkg:

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

  Multijets (ABCD Etmiss vs N_{tags})

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



Photon + b-jet + MET

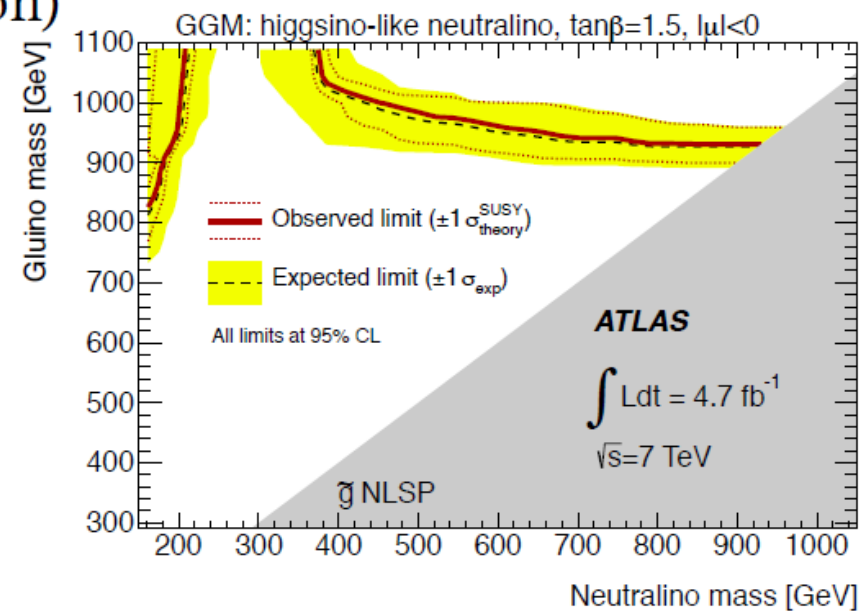
- No excess obs. → 95% CL limits
  (profile likelihood ratio method, CL_s criterion)

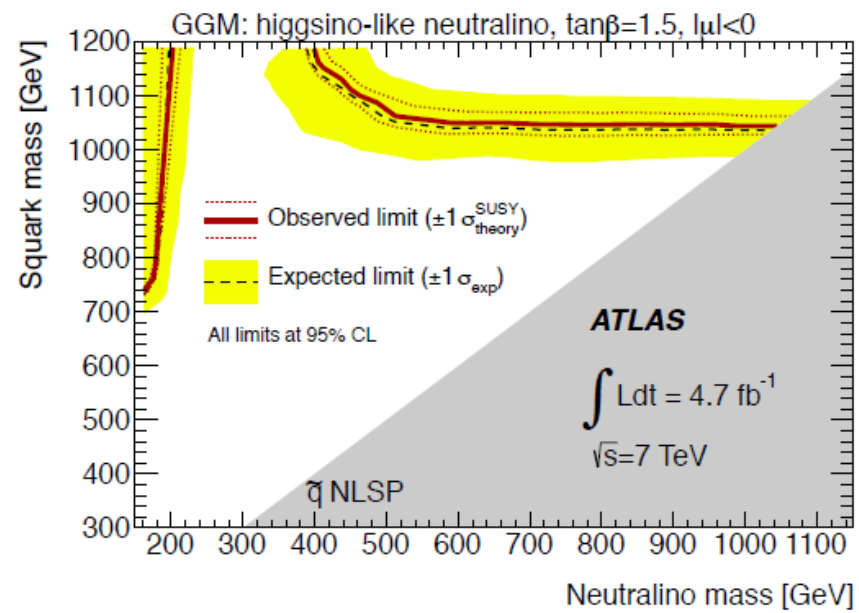
- $\sigma_{vis} < 1.6$ fb

- 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**

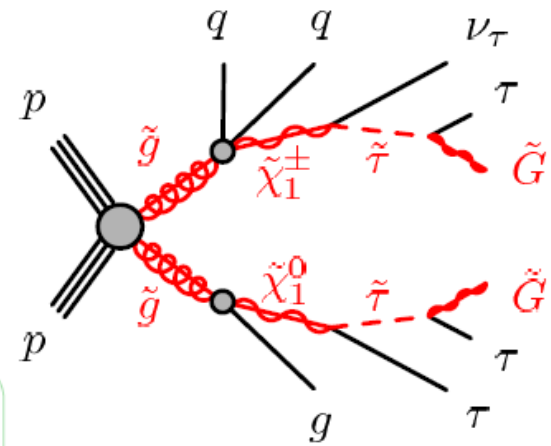
  - $220 \text{ GeV} < m(\tilde{\chi}_1^0) < 380$ GeV **excluded regardless gluino or squark masses!**
    (on the basis of the expected weak production)





Stau NLSP: tau+jets+MET

- GMSB $\tilde{\tau}$ NLSP → many taus in final state
- Event selection
  - 1 ($\geq$ 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)

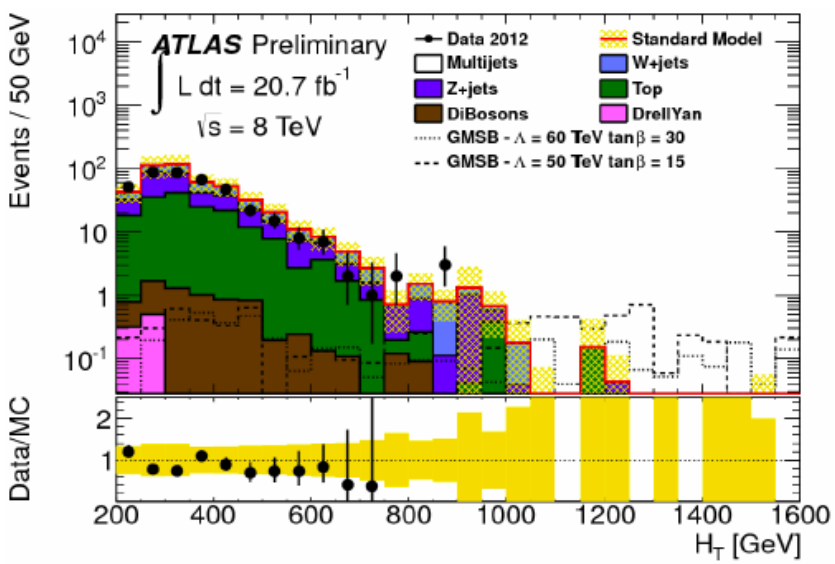


- 3 signal regions:

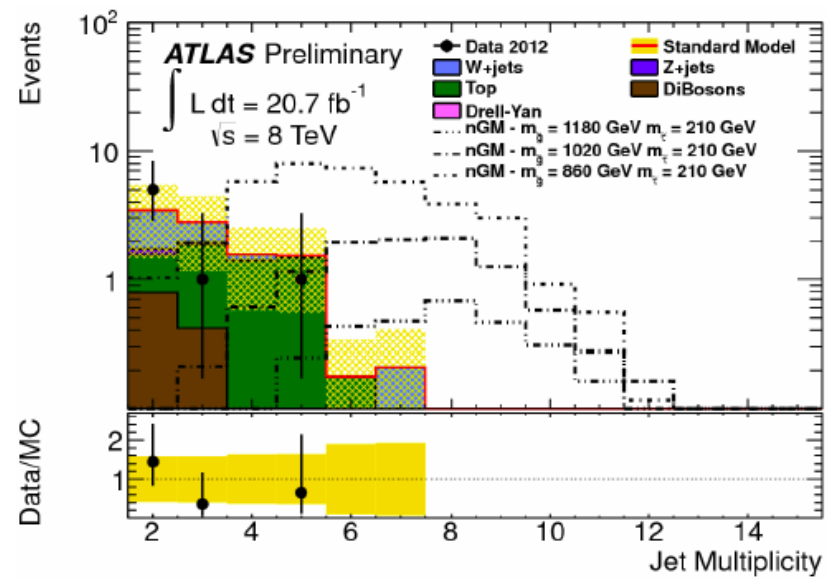
1τ	2τ GMSB	2τ nGM
$m_T^{\tau} > 140\text{GeV}$	$m_T^{\tau 1} + m_T^{\tau 2} \geq 150\text{GeV}$	$m_T^{\tau 1} + m_T^{\tau 2} \geq 250\text{GeV}$
$H_T \geq 800\text{GeV}$	$H_T \geq 900\text{GeV}$	$H_T \geq 600\text{GeV}$
		$N_{jet} \geq 4$

- Dominant bkg: W/Z+jets, top production 2D CR (m_T vs $n_{b\text{-tags}}$)

  QCD multijets (ABCD τ_{ID} vs $\Delta\varphi$) , others (MC)



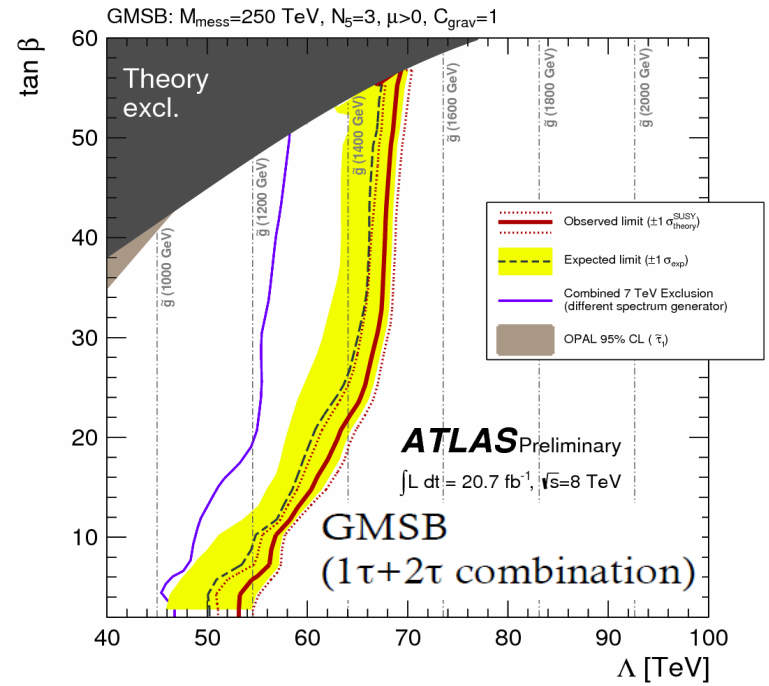
Final distribution of HT in the 1τ SR



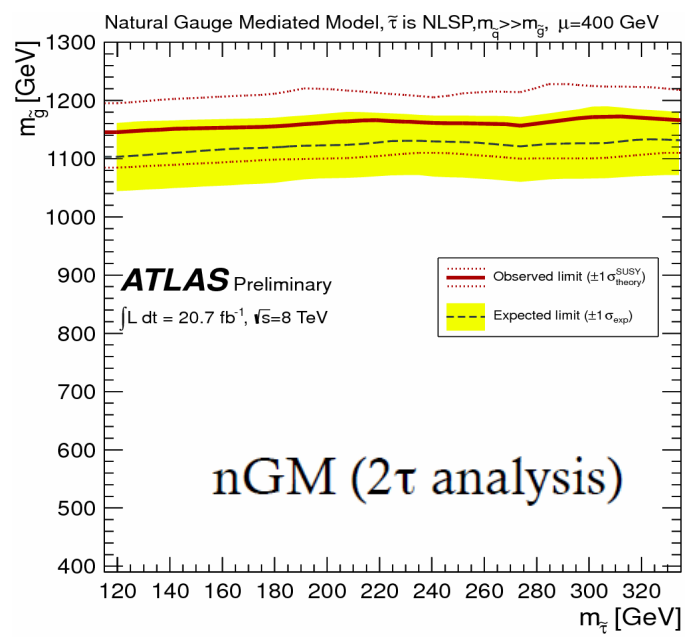
Final distribution of n_{jet} in the 2τ nGM SR

Stau NLSP: tau+jets+MET

- 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



- GMSB: Λ>51 TeV
- nGM: gluino > 1.14 TeV



ATLAS-CONF-2013-026

Long-lived slepton (stau) search

GMSB $\tilde{\tau}_1$ NLSP, decaying outside the ATLAS volume

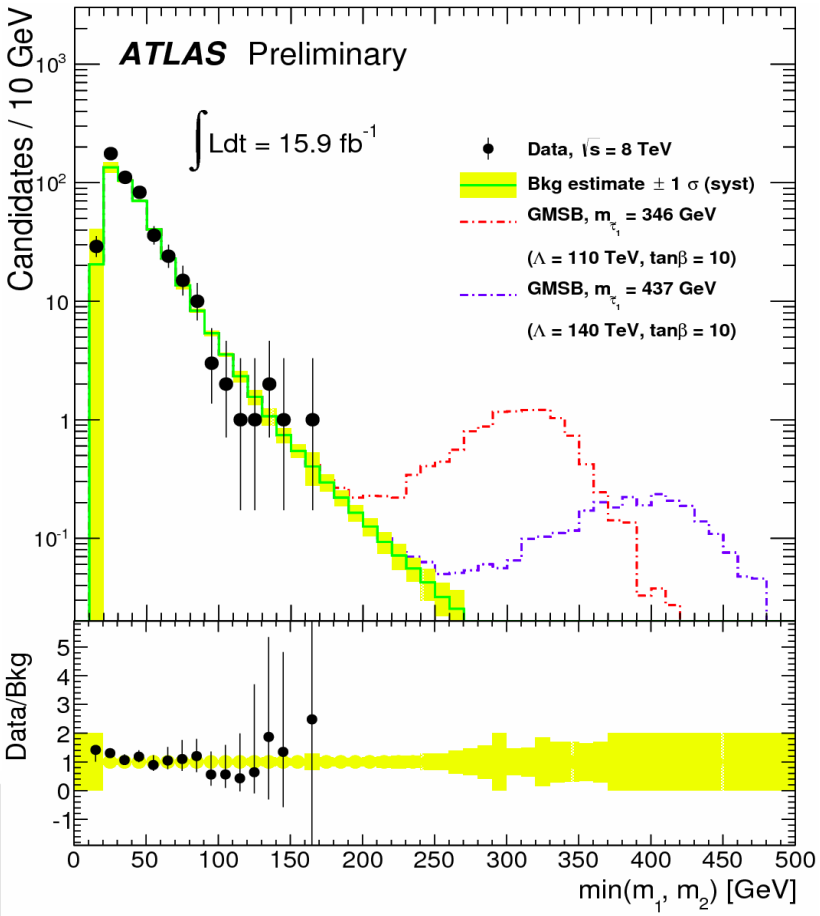
Event selection

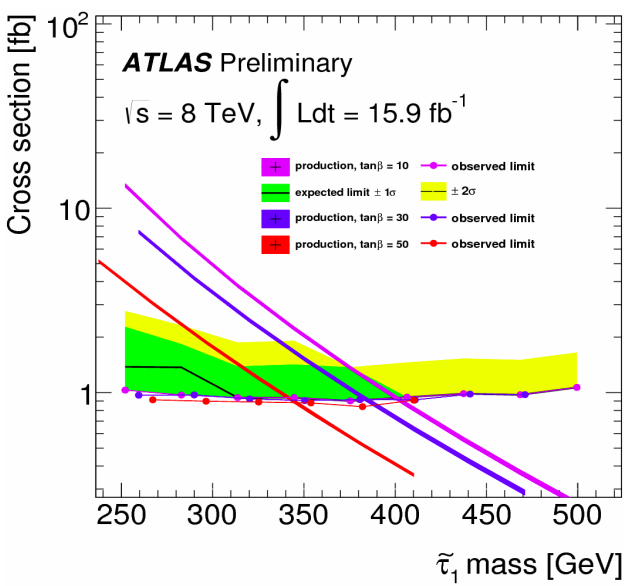
- two loosely identified muons, $p_T > 50$ GeV, $|\eta| < 2.5$,
- $|m_{\mu\mu} - m_Z| > 10$ GeV
- β measurement quality criteria
  - consistency among Pixel, Calo & Muon Spectrometer

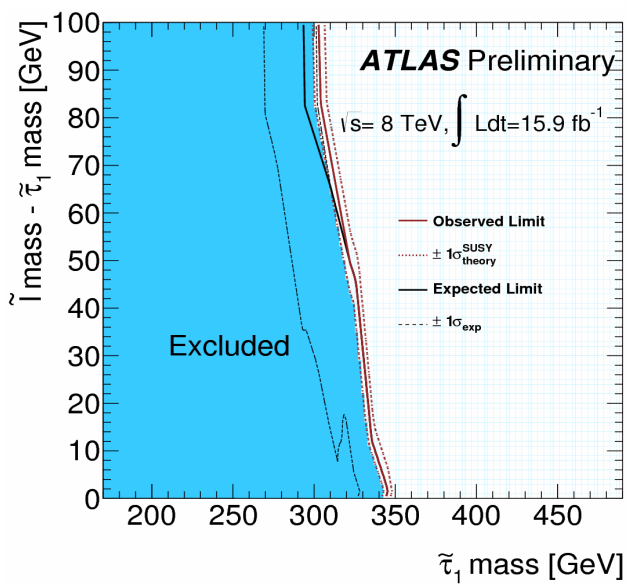
Signal selection :

- Lower Mass cut on two candidates $m = p / \beta\gamma$

Background : high-p_T muons with mis-measured β (data)







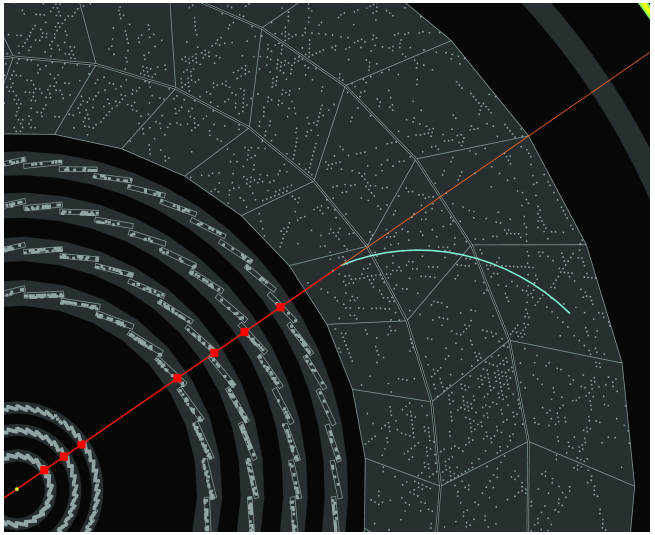
ATLAS-CONF-2013-058

Updating to full 2012 dataset, with improved calibrations…

Disappearing tracks: long-lived chargino

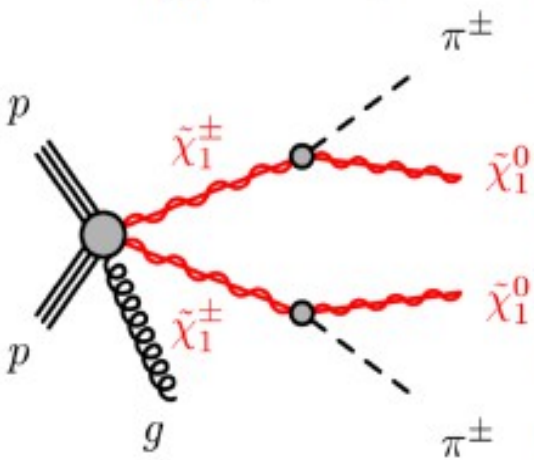
Characteristics

- LSP = pure Wino
- $\Delta m \approx 160$ MeV (between chargino and LSP)
  - Measurable lifetime $c\tau_{\chi^\pm} \approx O(10)$ cm
  - Decay inside ATLAS inner detector
- Chargino decays into a neutralino (MET) + soft pion (isn't reconstructed)



Trigger

Mono-jet (from ISR) + MET, with $\Delta\varphi(\text{jet,MET}) \approx \pi$

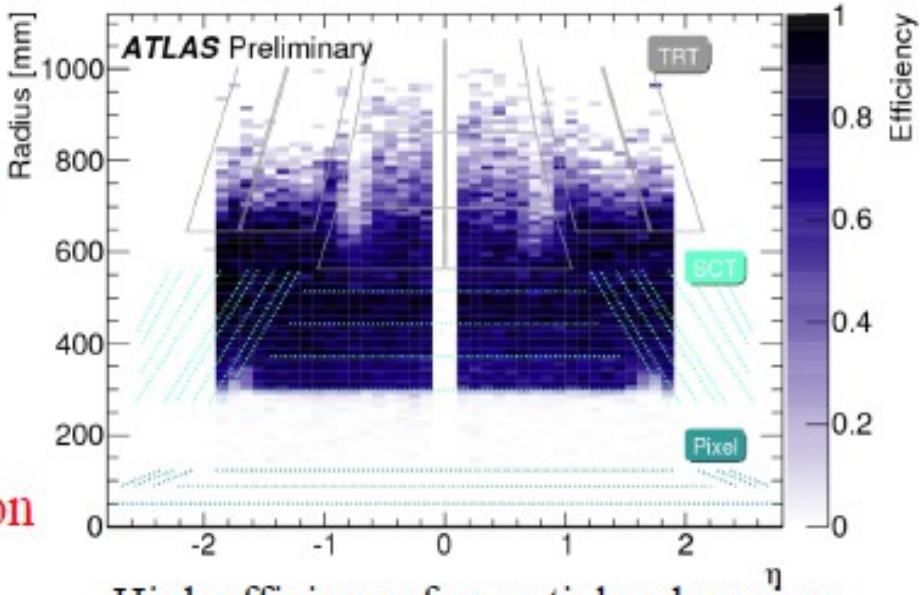


Selection

Select good, isolated high-p_T tracks with < 5 TRT hits

Veto events with leptons

Dedicated track reconstruction significantly improves the sensitivity to short lifetimes compared to previous analysis

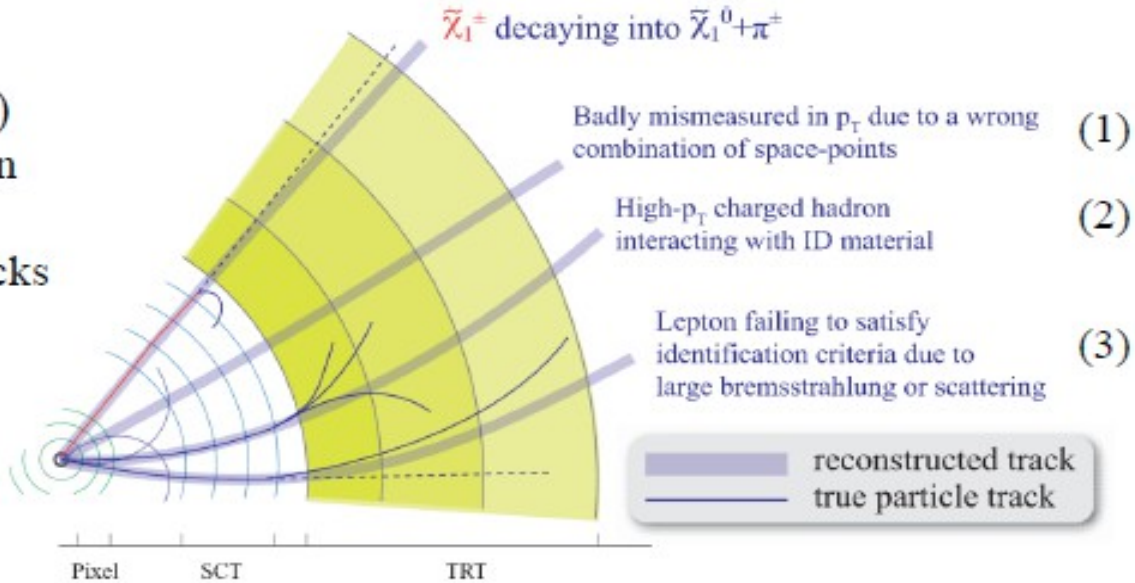


High efficiency for particles decaying after the PIXEL and before the TRT

Disappearing tracks: long-lived chargino

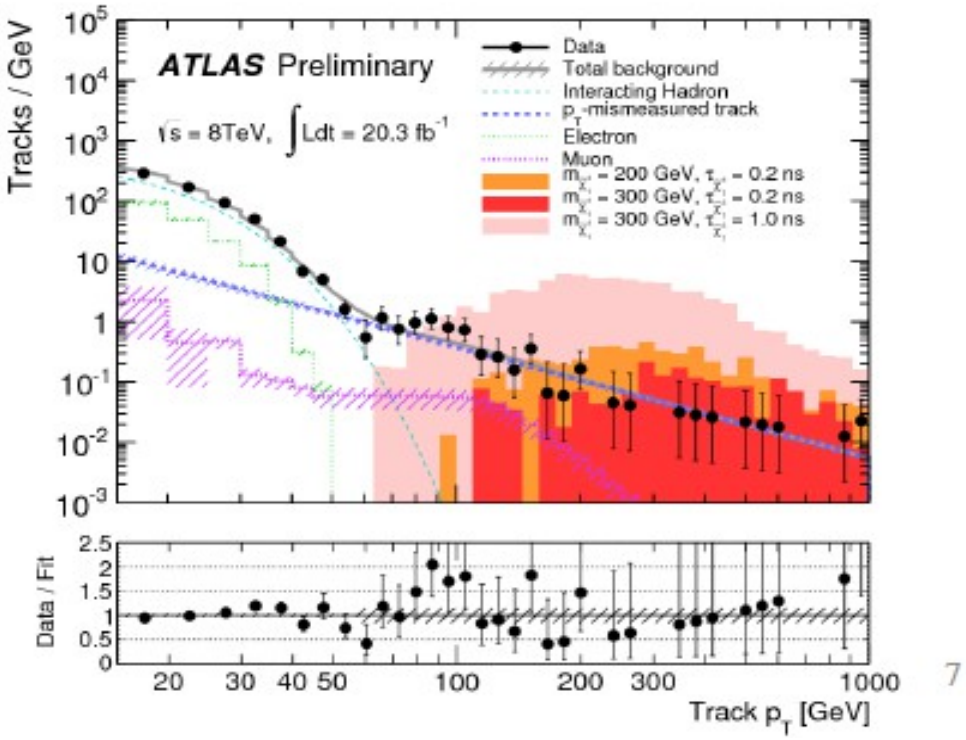
Three main background sources

1. p_T-mismeasured tracks (main source)
   - Wrong combination of seed-cluster in pixel detector
   - Wrong extension of pixel-seeded tracks
2. Interacting hadron tracks
   - Comes mainly from $W \rightarrow \tau\nu$
   - Large calorimeter activities
3. Unidentified leptons
   - Leptons which survive lepton veto



Background estimation

- Background tracks p_T-shape from data control samples
  - Unidentified-leptons normalization also determined from data control sample
- Signal tracks p_T-shape from MC
- Perform signal + background template fit for candidate tracks



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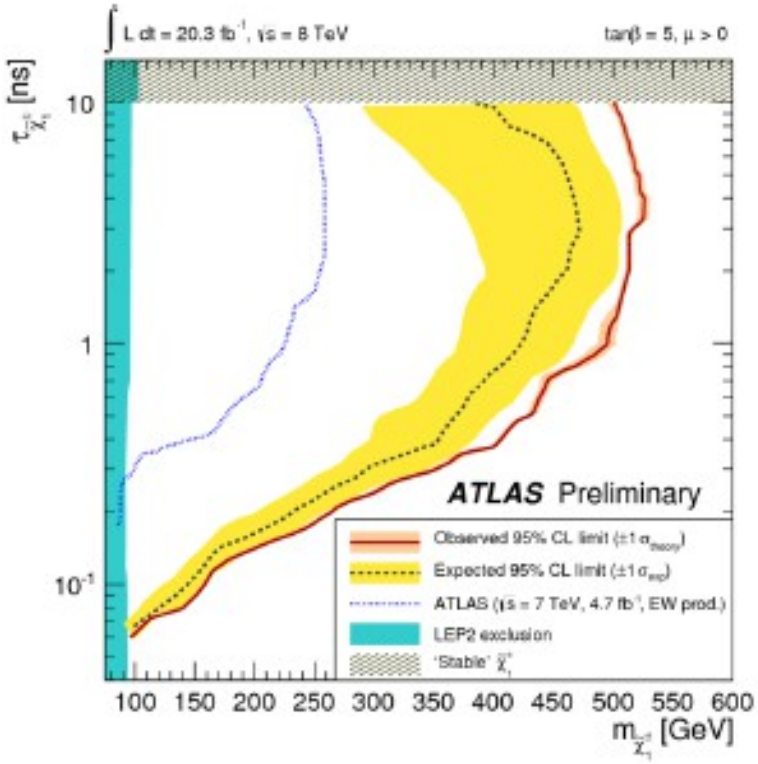
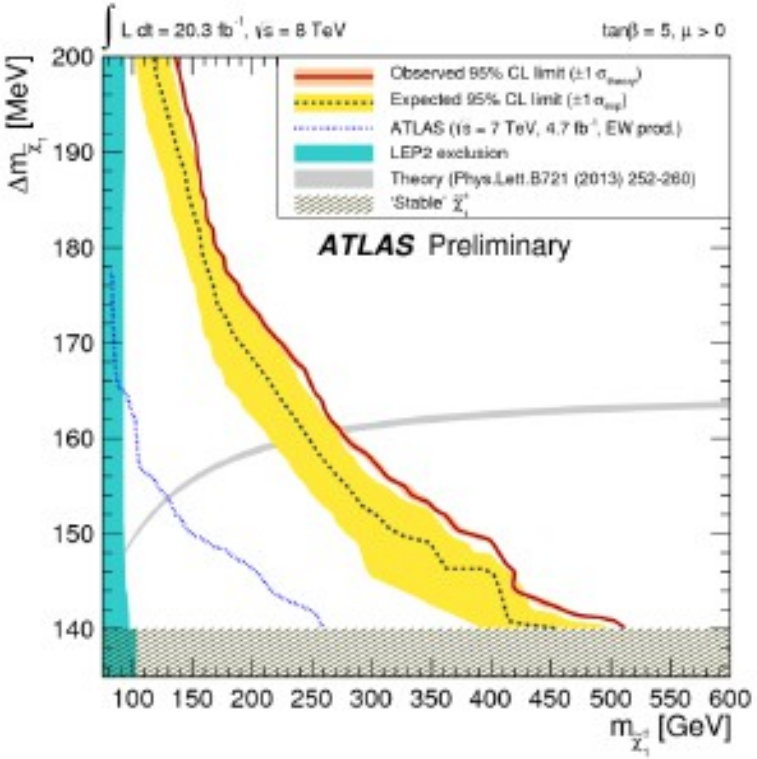
Disappearing tracks: long-lived chargino

Data consistent with background → Limit setting



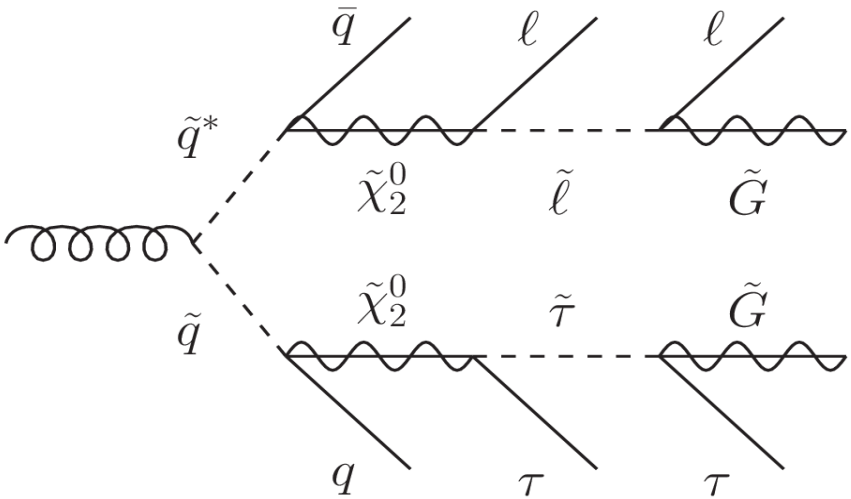


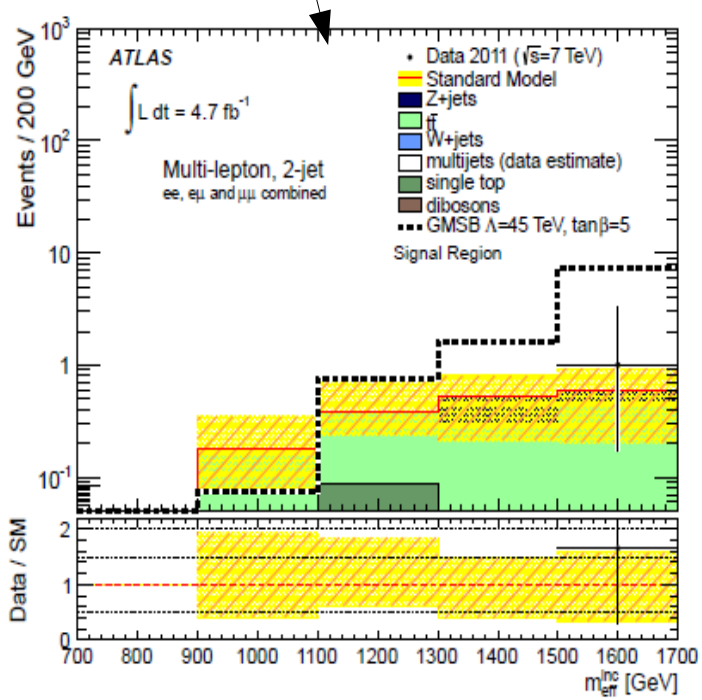
- In the high p_T region, observed number of events is a bit smaller than the fit result, so the observed limit is tighter than the expected limit.

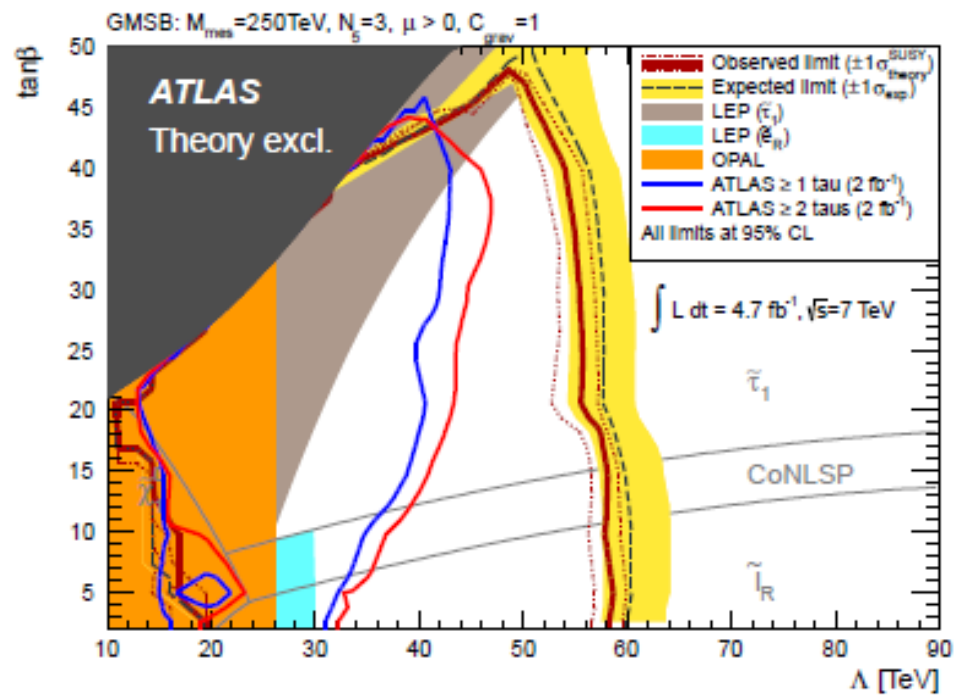
- In AMSB model with τ ~0.2 ns and Δm ~160 MeV, chargino mass up to 270 GeV is excluded.
- For longer chargino lifetimes of τ ~1-10 ns, chargino mass up to 520 GeV is excluded.

Stau / slepton co-NLSP: leptons+jets+MET

	multi-lepton 2-jet	multi-lepton 4-jet
Trigger	Single electron or muon (+jet)	
$N_{\rm lep}$	≥ 2	≥ 2
$p_{\rm T}^{\ell}$ (GeV)	25 (20)	25 (20)
$p_{\rm T}^{\ell 2}$ (GeV)	> 10	> 10
$N_{\rm jet}$	≥ 2	≥ 4
$p_{\rm T}^{\rm jet}$ (GeV)	$> 200{,}200$	$> 50{,}50{,}50{,}50$
$p_{\rm T}^{\rm add.jet}$ (GeV)	< 50	—
$E_{\rm T}^{\rm miss}$ (GeV)	> 300	> 100
$m_{\rm T}$ (GeV)	—	—
$E_{\rm T}^{\rm miss}/m_{\rm eff}$	—	0.2
$m_{\rm eff}^{\rm inc}$ (GeV)	—	> 650







Phys. Rev. D 86, 092002 (2012).

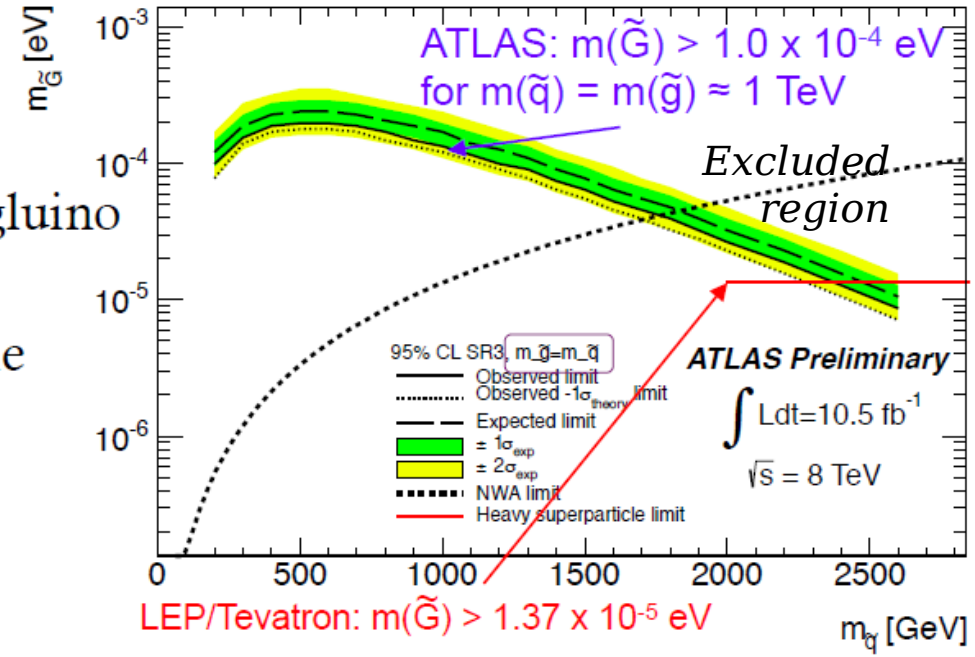
Other searches

Monojet+MET

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

- Associated production of gravitino + squark/gluino
- $\sigma \sim 1/m_{\tilde{G}}^2$ → constrain $m_{\tilde{G}}$!
- Gravitino mass probes the SUSY-breaking scale

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

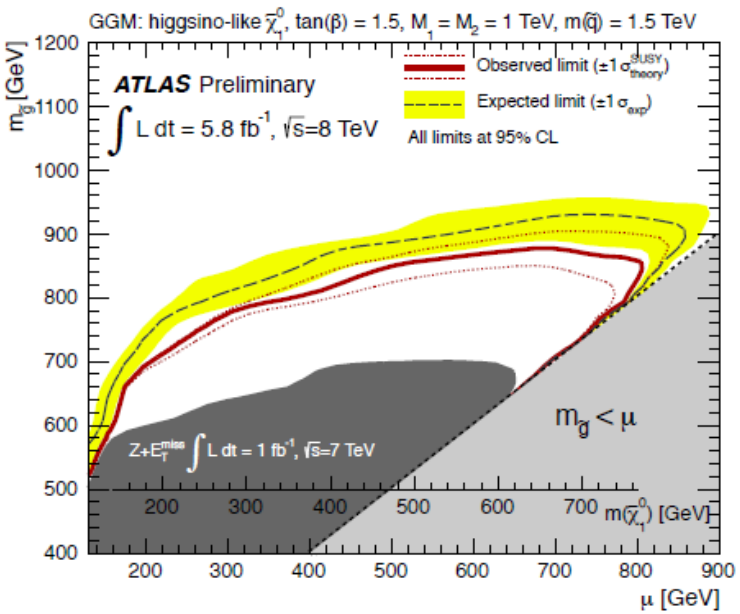


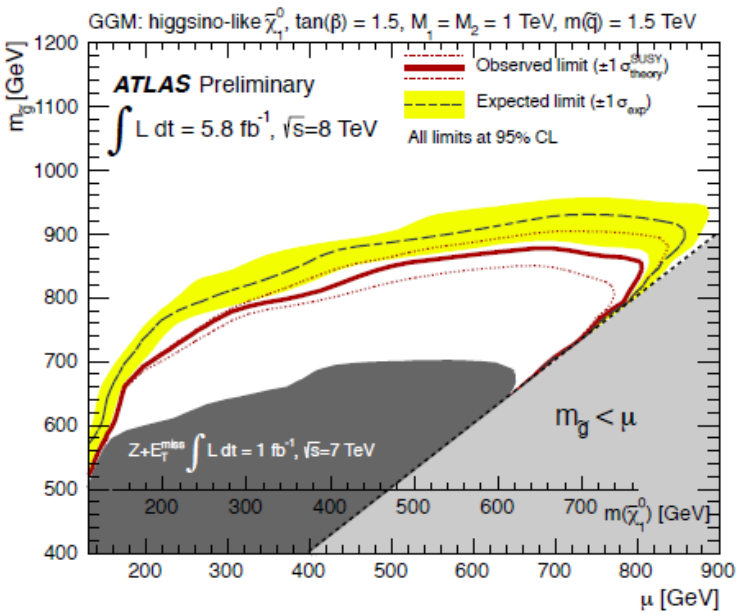
Z+jets+MET

ATLAS-CONF-2012-152

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

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



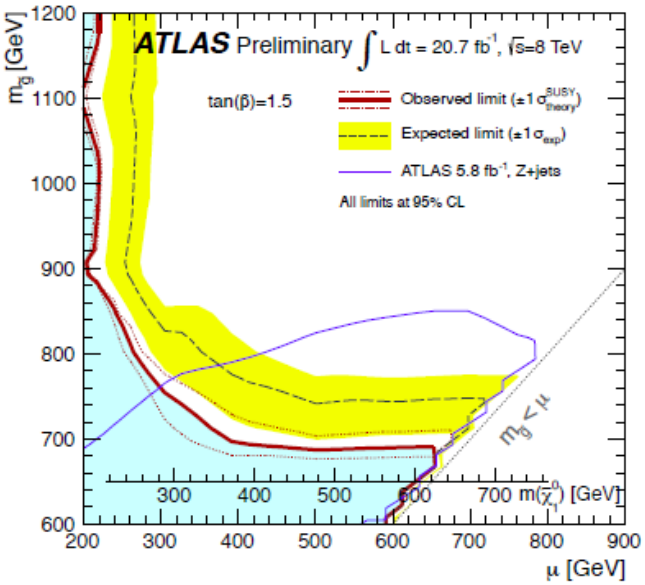


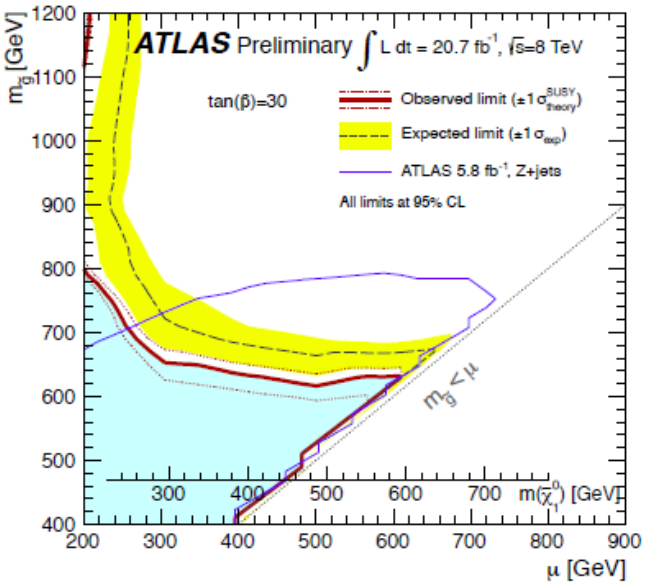
Other searches

4leptons+MET

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

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

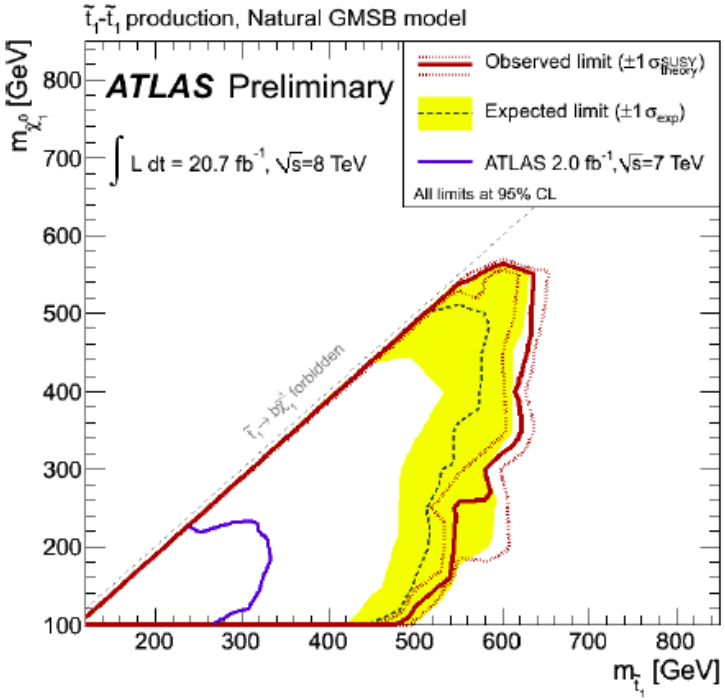




Z+b-jets+MET

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

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



Conclusions

- GMSB is an important SUSY model, with distinct phenomenology
  - Bino-like Neutralino NLSP → photons + MET (prompt or displaced!)
  - Wino-like Neutralino NLSP → photon + lepton + MET
  - Higgsino-like Neutralino NLSP → photon + b-jet + MET
  - Higgsino-like Neutralino NLSP → Z+jets+MET, multi-leptons + MET, Z+b-jets+MET analyses also have sensitivity
  - Stau NLSP → taus + MET (prompt or long-lived!)
  - Meta-stable chargino → disappearing tracks
  - Stau/slepton co-NLSP → leptons + jets + MET
  - Mono-jet + MET
  - Other analyses we should be exploring?

- We'll continue to update results using the full 2012 8 TeV dataset

- We look forward to 13/14 TeV data and higher luminosity!

Backup

GMSB models

Minimal GMSB :

- Mass spectrum depends on few parameters: $\mathbf{\Lambda, M_{mes}, N_5, \tan(\beta), C_{grav}, sign(\mu)}$

  Parameters (general model has 124):

  → Λ: Breaking scale
  → M: Mass scale of the messengers
  → $\tan\beta$: Ratio of Higgs vacuum expectation values
  → N: Number of messenger chiral supermultiplets
  → sign(μ): Sign of the Higgs mass parameter
  → C_{grav}: Scale factor of the Gravitino mass → lifetime of NLSP

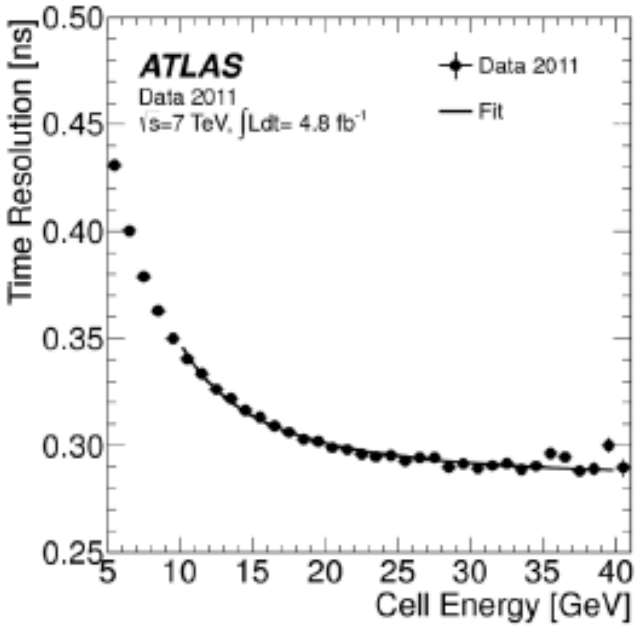
General Gauge Mediation (GGM) :

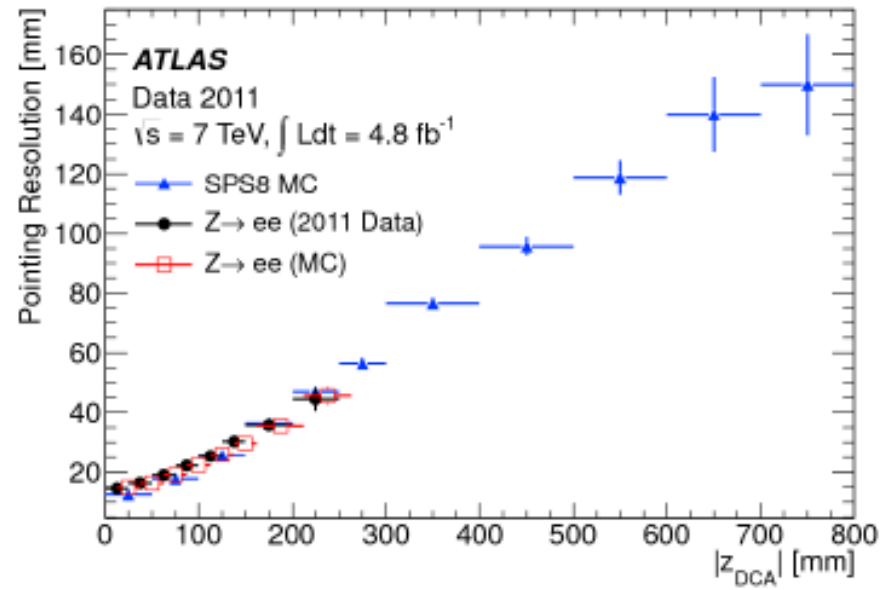
- no specific SUSY mass hierarchy for (un)colored states → any MSSM sp can be NLSP
- neutralino's nature depends on: **M1, M2, μ, tan(β)**

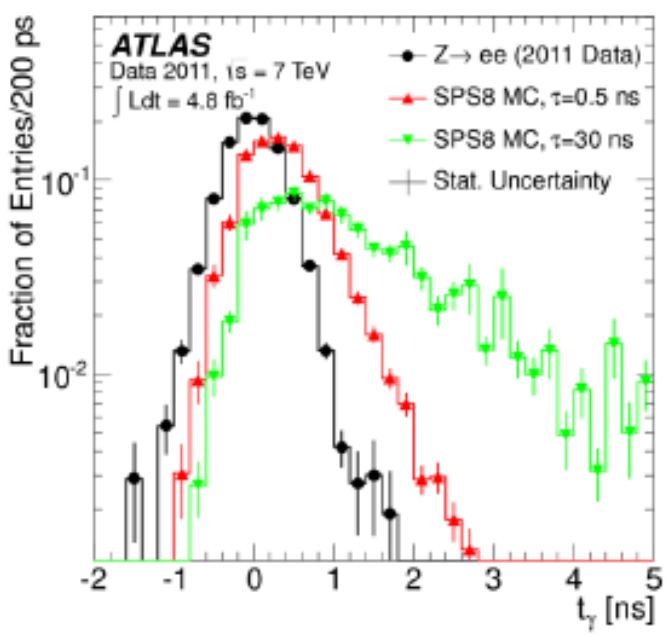
Natural Gauge Mediation (nGM) :

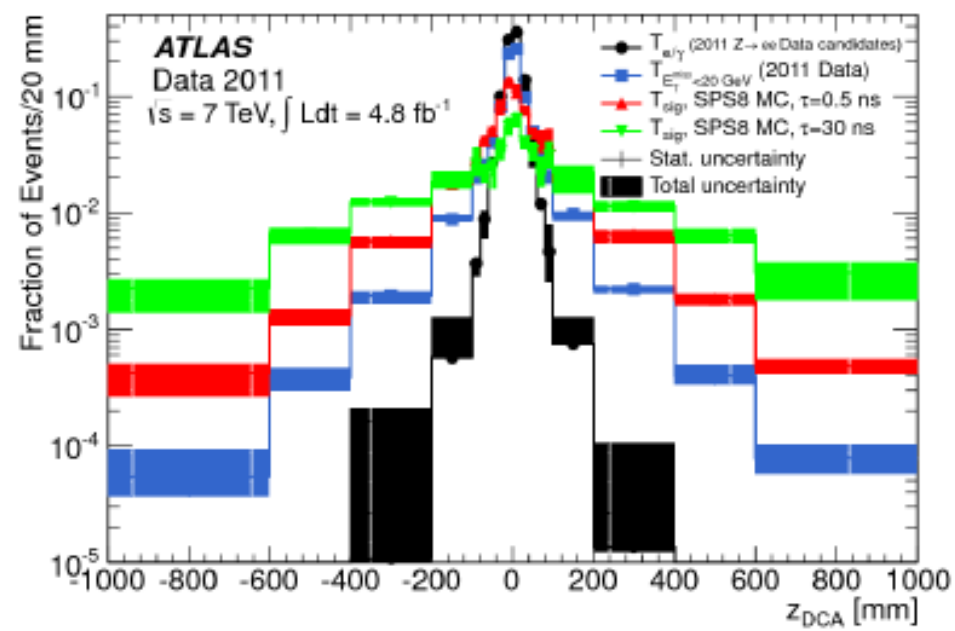
- decouple all sparticles not related to fine-tuning of Higgs sector
- top squarks and gluinos as only light coloured sparticles

Non-Pointing Photons









Disappearing Tracks

Comparisons between excess region and nearby track-p_T regions