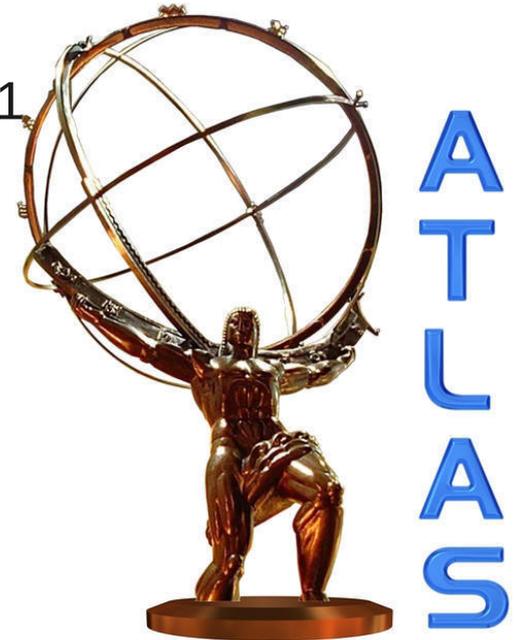
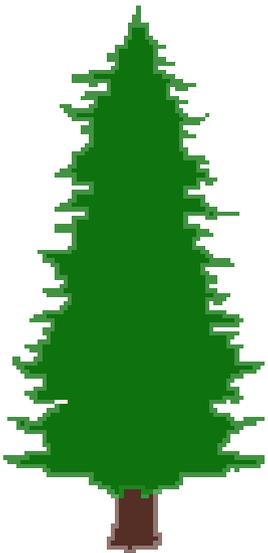


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# SUSY Searches with Photons in ATLAS

**Daniel Damiani (UC Santa Cruz)**  
on behalf of the ATLAS Collaboration

SUSY Workshop at LBNL – Oct 19-21, 2011





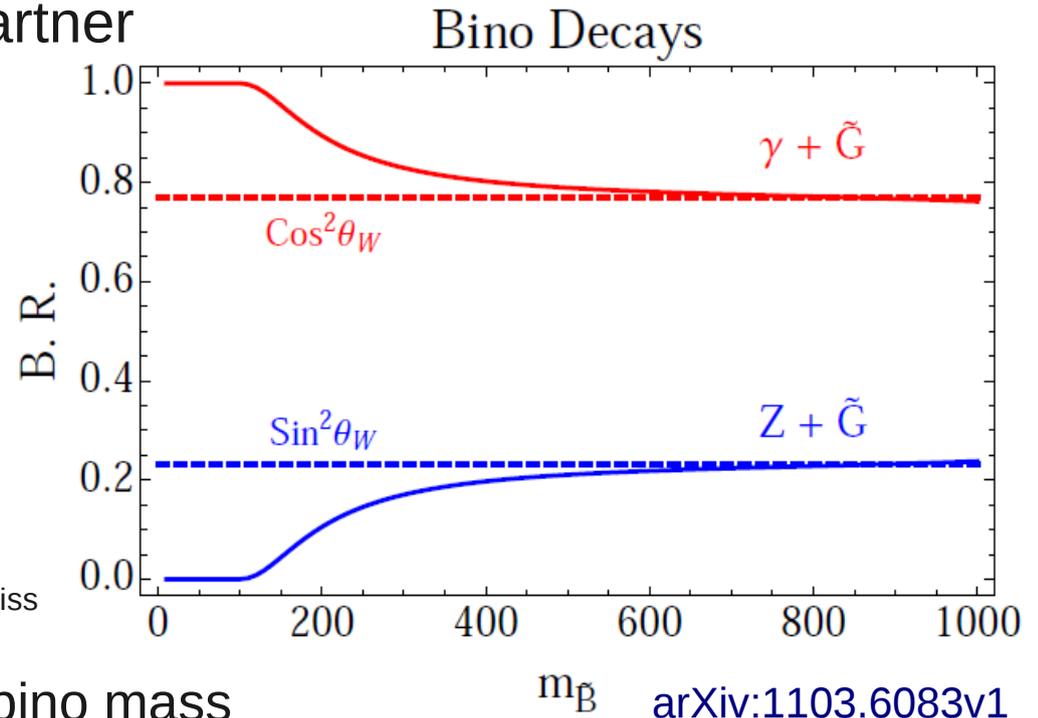
# Photon Signatures from GMSB

- Bino – U(1) gauge field superpartner
- Purely bino-like NLSP

- $|M_1| \ll \mu$  and  $|M_1| < |M_2|$
- The bino decays to photon or Z plus a gravitino
- High diphoton branching fraction:  $\sim 0.8-1.0$
- Photon kinematics and  $E_T^{\text{miss}}$

- Determined mostly by bino mass
- Not strongly correlated to rest of the cascade

- The current analysis was optimized for a prompt bino-like NLSP
- Non bino-like NLSP – other photon signatures are possible
  - Photon + b – higgsino-like NLSP
  - Photon + lepton – wino-like NLSP



# Event Selections

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- Maximize sensitivity to the diphoton +  $E_T^{\text{miss}}$  parameter space
  - Selections based only on NLSP decay products
  - Limit dependence on cascade down to the NLSP
- Common cuts (signal and control samples):
  - Trigger – two loose criteria em clusters with  $p_T > 20$  GeV
  - Primary vertex  $> 4$  tracks
  - Reject events with jets with **bad** characteristics (from noise, cosmics, beam bkgd, detector acceptance holes)
- Require two selected photons – details on next slide
- **No** requirements on number of jets – preserves sensitivity
- $E_T^{\text{miss}} > 125$  GeV

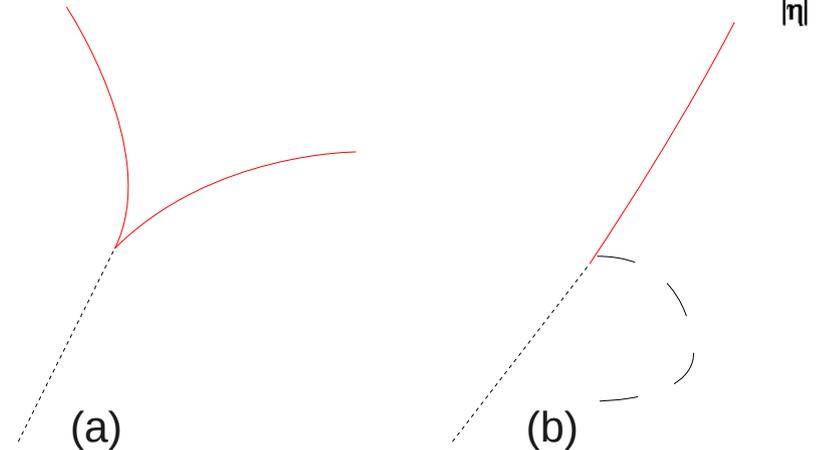
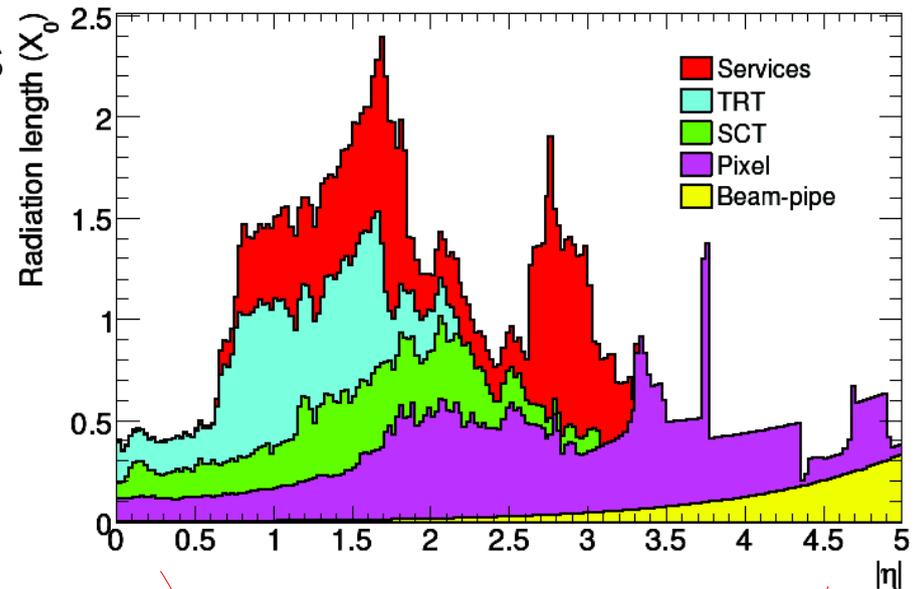
# Detailed Photon Selections

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- Photon kinematic/isolation selections
  - $p_T > 25$  GeV
  - $|\eta| < 1.81$  also exclude  $1.37 < |\eta| < 1.52$  (calorimeter crack)
  - Tight shower shape requirements
  - Calorimeter iso:  
(Energy in  $\Delta R < 0.2$ , excluding core cluster)  $< 5$  GeV
    - Includes out-of-cluster leakage and pileup corrections.
  - Not in/near a distinct jet ( $0.2 < \Delta R_{yjet} < 0.4$ )
- Photon cleaning cuts
  - Not in a bad calorimeter region
  - Calo. timing cut ( $< 10$  ns)
    - Removes photons from cosmics
    - Especially important for the control samples
  - Additional minor cleaning

# Photon Conversions

- High fraction of photons convert due to material before calorimeter
- Aggressive recovery of conversions
  - Pro: preserves efficiency
  - Con: additional fakes from electrons
  - Optimal choice based on Monte Carlo studies
- Two conversion types:
  - Two-track (a)
  - Single-track (b)
  - Single track conv. with hits that may have been lost due to dead modules in the first layer are rejected



Tracks: reconstructed ———; non-reconstructed - - -

# Background Modeling Strategy

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- Use data-driven approach as much as possible
- Instrumental  $E_T^{\text{miss}}$  background
  - $\gamma\gamma$ ,  $\gamma$ +jet, or n-jet events – fake  $E_T^{\text{miss}}$  and jets faking photons
  - Data-driven estimation
- Genuine  $E_T^{\text{miss}}$  background
  - Fake photons from electrons + real  $E_T^{\text{miss}}$ 
    - $t\bar{t}$ ,  $W$ +jets, and  $W$ + $\gamma$
    - Data-driven estimation
  - Irreducible backgrounds – real photons and real  $E_T^{\text{miss}}$ 
    - $Z\gamma\gamma$  and  $W\gamma\gamma$
    - Modeled using Monte Carlo
- Cosmic background – found to be negligible
  - Used empty bunch triggered events

# QCD Control Sample

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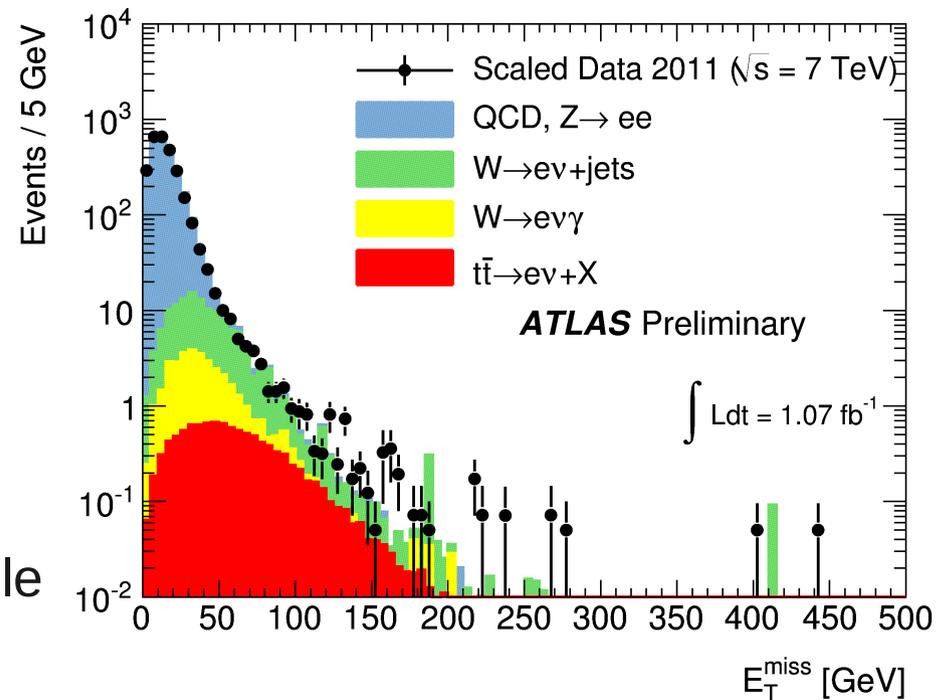
- Require the common trigger and event cleaning
- Require one 'pseudo' photon
  - Looser shower shape requirements
  - Must fail the tight requirements
  - All other cuts identical to signal photons
  - Implicit second electromagnetic object from trigger
- Veto on identified electrons – removes W contamination
- Normalized to the  $\gamma\gamma$  sample for  $E_T^{\text{miss}} < 20$  GeV
- $Z \rightarrow ee$  sample  $E_T^{\text{miss}}$  shape used to model  $\gamma\gamma$ 
  - $Z \rightarrow ee$ : softer  $E_T^{\text{miss}}$  spectrum – like  $\gamma\gamma$  events
  - Pseudo  $\gamma$ : harder  $E_T^{\text{miss}}$  spectrum – like dijet,  $\gamma$ +jet events
  - Fits to intermediate  $E_T^{\text{miss}}$  favor pseudo photon shape
  - $Z \rightarrow ee$  shape difference taken as a systematic

# e/γ Control Sample

- Require the common trigger and event cleaning
- Require exactly one signal photon and one electron
  - Electron kinematic/isolation cuts identical to photon
- Scaled by an electron to photon scale factor
  - Scale factor determined from a tag-and-probe Z sample
  - 5 to 17% – varies with  $\eta$

- QCD and  $Z \rightarrow ee$  contamination at low  $E_T^{\text{miss}}$

- QCD sample  $E_T^{\text{miss}}$  template is normalized to e/γ for  $E_T^{\text{miss}} < 20$  GeV
- Normalized QCD sample subtracted from the e/γ sample



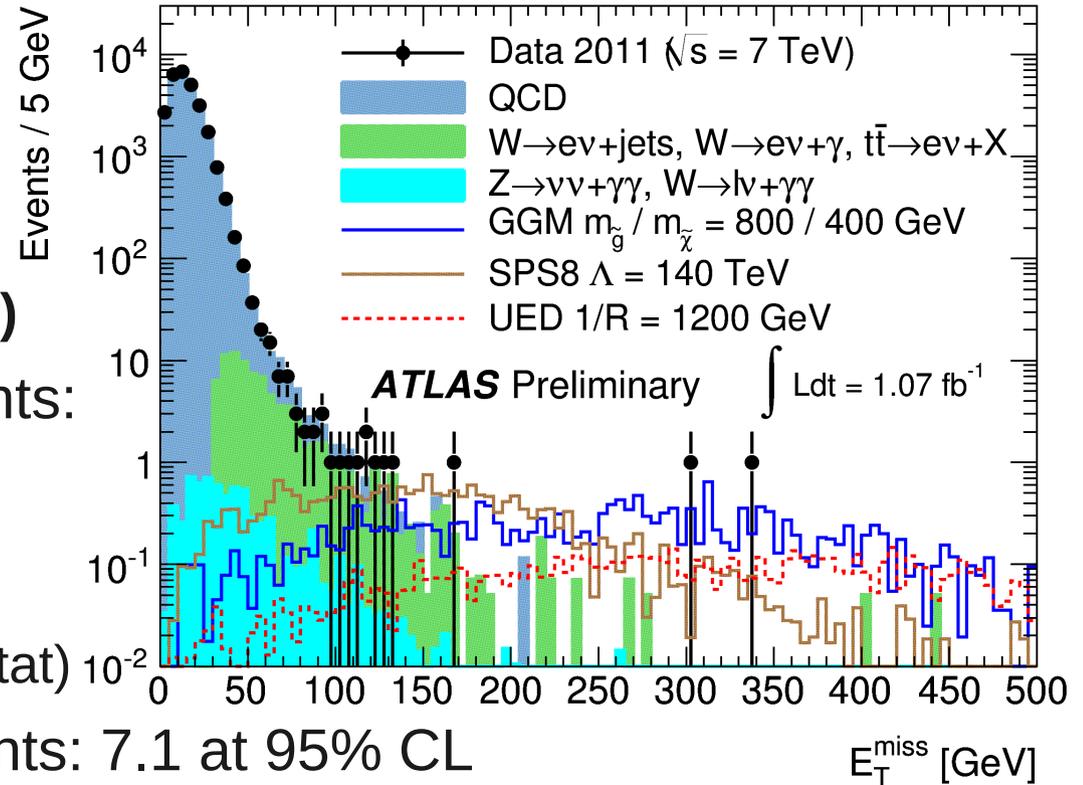
# Results

- Events with  $E_T^{\text{miss}} > 125$  GeV with  $1.07 \text{ fb}^{-1}$ :

- Observed: **5**
- Predicted background:  **$4.1 \pm 0.6(\text{stat}) \pm 1.4(\text{syst})$**

- Breakdown of bkgd components:

- QCD:  $0.8 \pm 0.3(\text{stat})$
- W/ttbar:  $3.1 \pm 0.5(\text{stat})$
- Irreducible:  $0.23 \pm 0.05(\text{stat})$

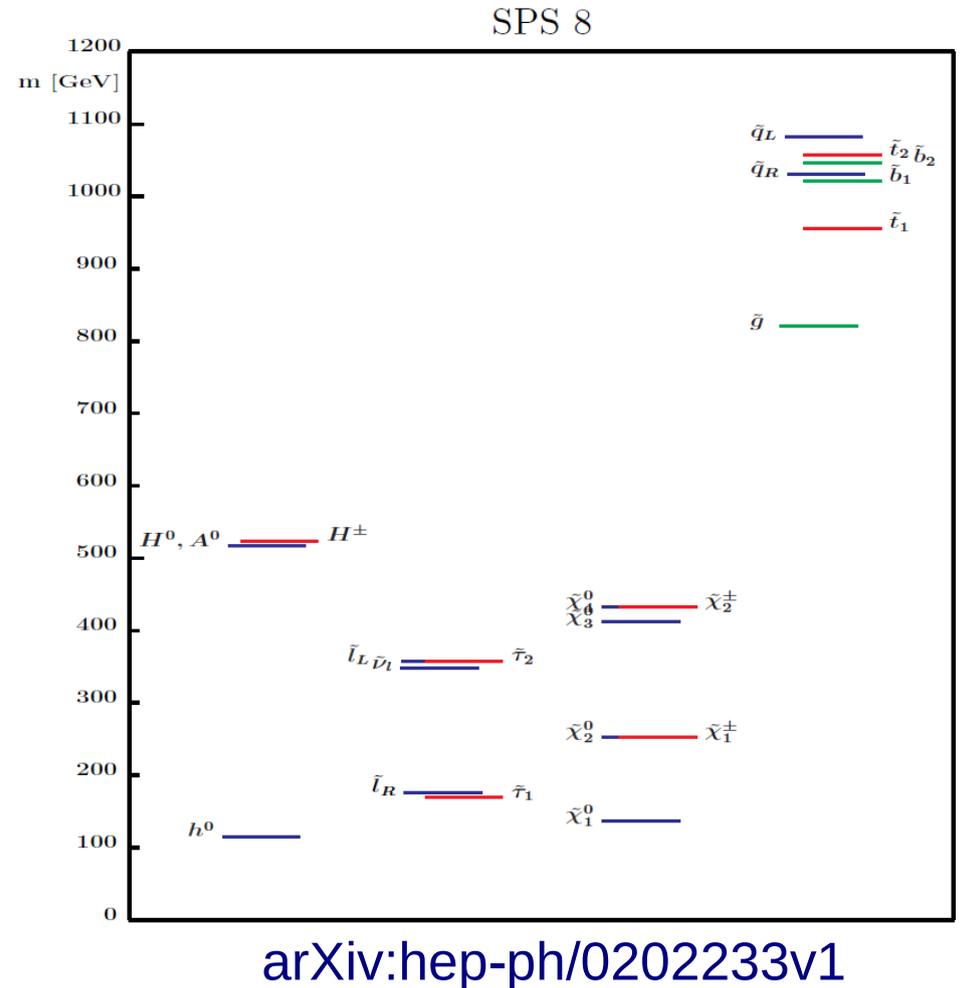


- Limit on number of signal events: **7.1 at 95% CL**

$E_T^{\text{miss}}$ range [GeV]	Data events	Predicted background events				Expected signal events		
		Total	QCD	$W/t\bar{t}(\rightarrow e\nu) + X$	Irreducible	GGM	SPS8	UED
0 - 20	20881	-	-	-	-	$0.20 \pm 0.05$	$0.22 \pm 0.04$	$0.02 \pm 0.01$
20 - 50	6304	$5968 \pm 29$	$5951 \pm 28$	$13.3 \pm 8.1$	$3.6 \pm 0.3$	$0.45 \pm 0.08$	$1.5 \pm 0.1$	$0.11 \pm 0.01$
50 - 75	86	$87.1 \pm 3.3$	$60.9 \pm 2.8$	$25.2 \pm 1.7$	$1.0 \pm 0.2$	$0.48 \pm 0.08$	$2.2 \pm 0.1$	$0.14 \pm 0.01$
75 - 100	11	$14.7 \pm 1.2$	$6.7 \pm 0.9$	$7.4 \pm 0.8$	$0.52 \pm 0.10$	$0.8 \pm 0.1$	$2.1 \pm 0.1$	$0.15 \pm 0.01$
100 - 125	6	$4.9 \pm 0.7$	$1.6 \pm 0.4$	$3.0 \pm 0.5$	$0.32 \pm 0.08$	$1.2 \pm 0.1$	$2.5 \pm 0.1$	$0.29 \pm 0.02$
> 125	5	$4.1 \pm 0.6$	$0.8 \pm 0.3$	$3.1 \pm 0.5$	$0.23 \pm 0.05$	$17.2 \pm 0.5$	$13.0 \pm 0.3$	$9.67 \pm 0.11$

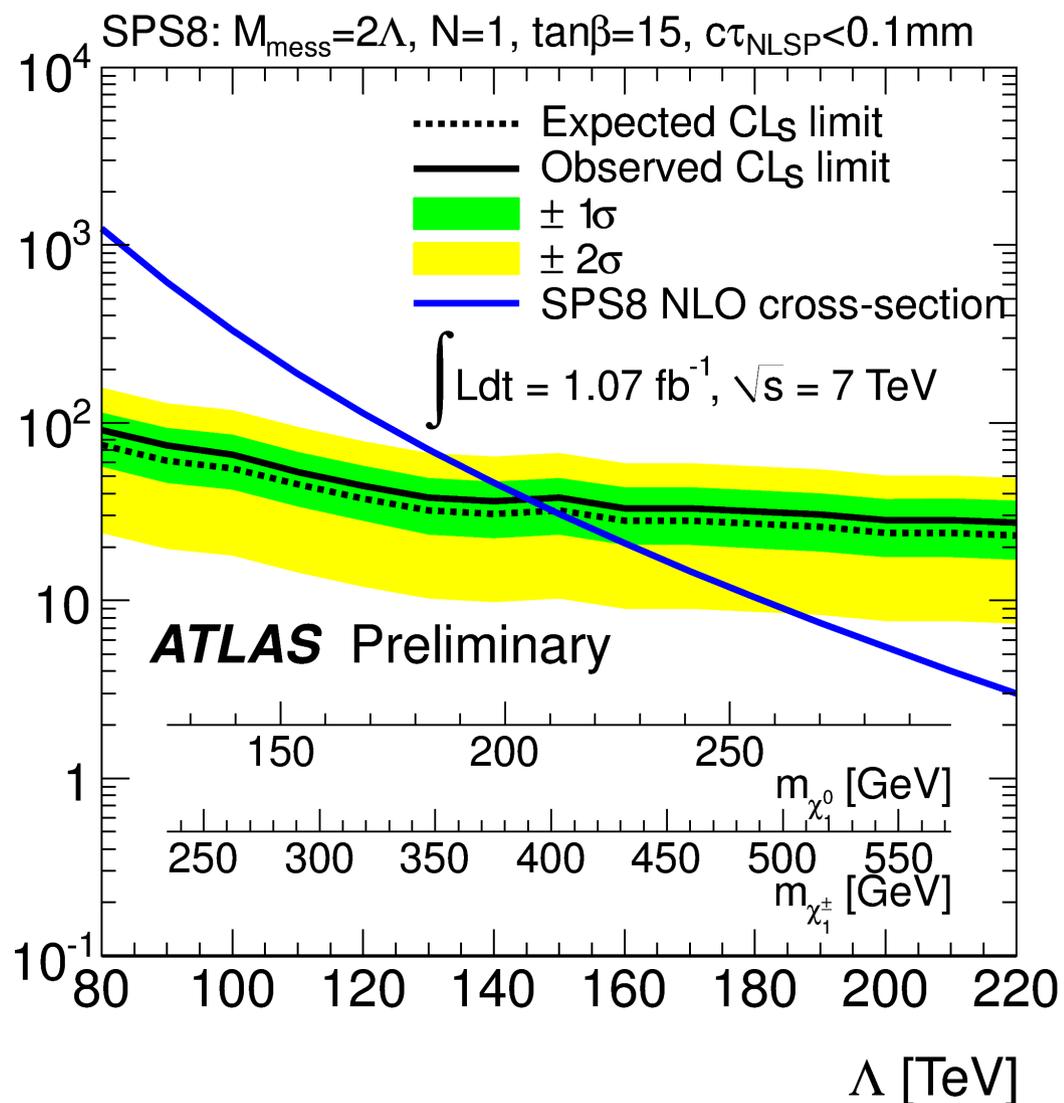
# mGMSB / SPS8

- Minimal GMSB – six input parameters
- SPS8 ([arXiv:hep-ph/0202233v1](https://arxiv.org/abs/hep-ph/0202233v1))
  - $\Lambda = \text{free}$                       –  $M_{\text{mes}} = 2\Lambda$
  - $N_5 = 1$                                 –  $\tan(\beta) = 15$
  - $\text{sign}(\mu) > 0$                       –  $C_{\text{grav}} = 1$
- Bino-like NLSP
- Mostly direct neutralino/chargino production at the LHC
- Other general features:
  - Gluinos/squark mass  $>$  neutralino/chargino mass
  - Sleptons – intermediate masses



# Limits – SPS8

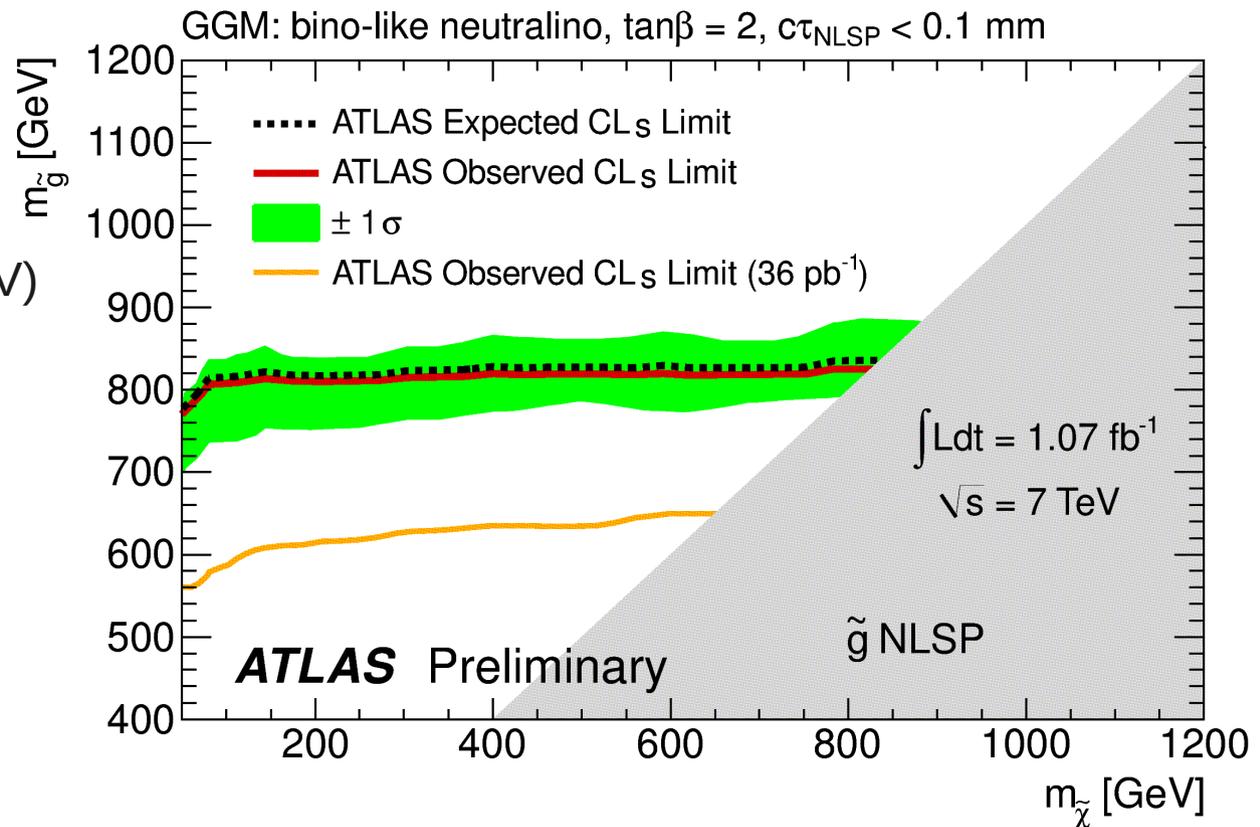
- Current ATLAS limit:
  - $\Lambda > 145$  TeV at 95 % CL<sub>S</sub> [fb]
- Previous results:
  - $\Lambda > 124$  TeV from D0  
([arXiv:1008.2133v1](https://arxiv.org/abs/1008.2133v1))
  - $\Lambda > \sim 107$  TeV from CDF  
([arXiv:0910.3643v2](https://arxiv.org/abs/0910.3643v2))
- NLSP mass:  
 $m(X_1^0) > \sim 205$  GeV



# Limits – General Gauge Mediation

- General Gauge Mediation (GGM) – Assumes fewer relations between the masses of the sparticles ([arXiv:0801.3278v3](https://arxiv.org/abs/0801.3278v3))
- Current ATLAS limit:  $M_{\text{gluino}} > 776 \text{ GeV}$  for  $M_{\text{bino}} > 50 \text{ GeV}$
- GGM grid:

- Parameters varied:
  - $M_1$  (50 - 1190 GeV)
  - $m_{\text{gluino}}$  (400 - 1200 GeV)
- $M_2 = 1.5 \text{ TeV}$ ,  
 $\mu = 1.5 \text{ TeV}$ ,  
 $\tan(\beta) = 2$
- All other sparticle masses = 1.5 TeV
- Only gluino production



# Theory Uncertainties

- NLO cross sections from Prospino 2.1
- Cross-section uncertainties
  - PDF – CTEQ6.6M error sets
  - Renormalization scale – scale up/down by factor 2
- Large cross-section uncertainties

- GGM – 20 to 49%
- SPS8 – 5.1 to 10.1%
- Difference from dominate production mechanisms
- Large uncertainties for heavy gluinos

Source of uncertainty	Uncertainty		
	GGM	SPS8	UED
Integrated luminosity	3.7%	3.7%	3.7%
Trigger	0.6%	0.6%	0.6%
Photon identification	3.9%	3.9%	3.7%
Photon isolation	0.6%	0.6%	0.5%
Pileup	1.3%	1.3%	1.6%
$E_T^{\text{miss}}$ reconstruction and scale	1.7%	5.6%	0.7%
LAr readout	1.0%	0.7%	0.4%
Signal MC statistics	2.9%	2.3%	1.8%
Total signal uncertainty	6.6%	8.3%	6.0%
PDF and scale	31%	5.5%	–
Total	32%	10%	6.0%

- Much larger than acceptance uncertainties for GGM grid
- Theory uncertainties used in the limits

# Future Plans

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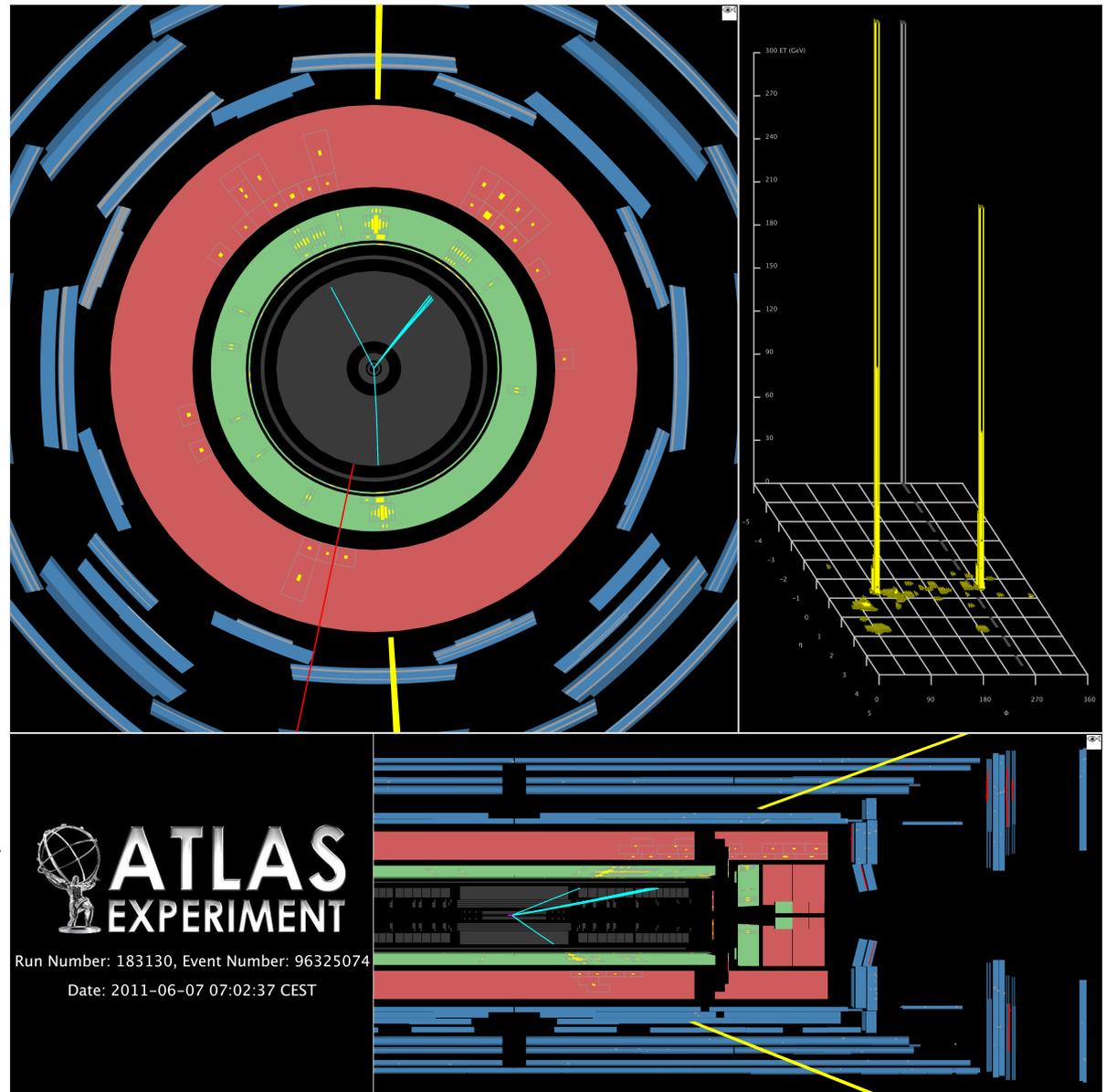
- Planned updates for diphoton +  $E_T^{\text{miss}}$  channel
  - Update for full 2011 LHC dataset ( $\sim 4\text{-}5 \text{ fb}^{-1}$ )
  - Look at  $m_{\text{squark}}$  vs.  $m_{\text{bino}}$  GGM grids
  - Re-optimize cuts
  - Improve rejection of fakes – particularly from electrons
- New search channels (planned for the full 2011 dataset)
  - Non-prompt photon searches
    - NLSP lifetime  $> 0 \rightarrow$  photons not pointing to collision vertex
    - Different selection criteria needed
  - Non bino-like GGM searches
    - Photon + b-jet searches
    - Photon + lepton searches

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# Backup Slides

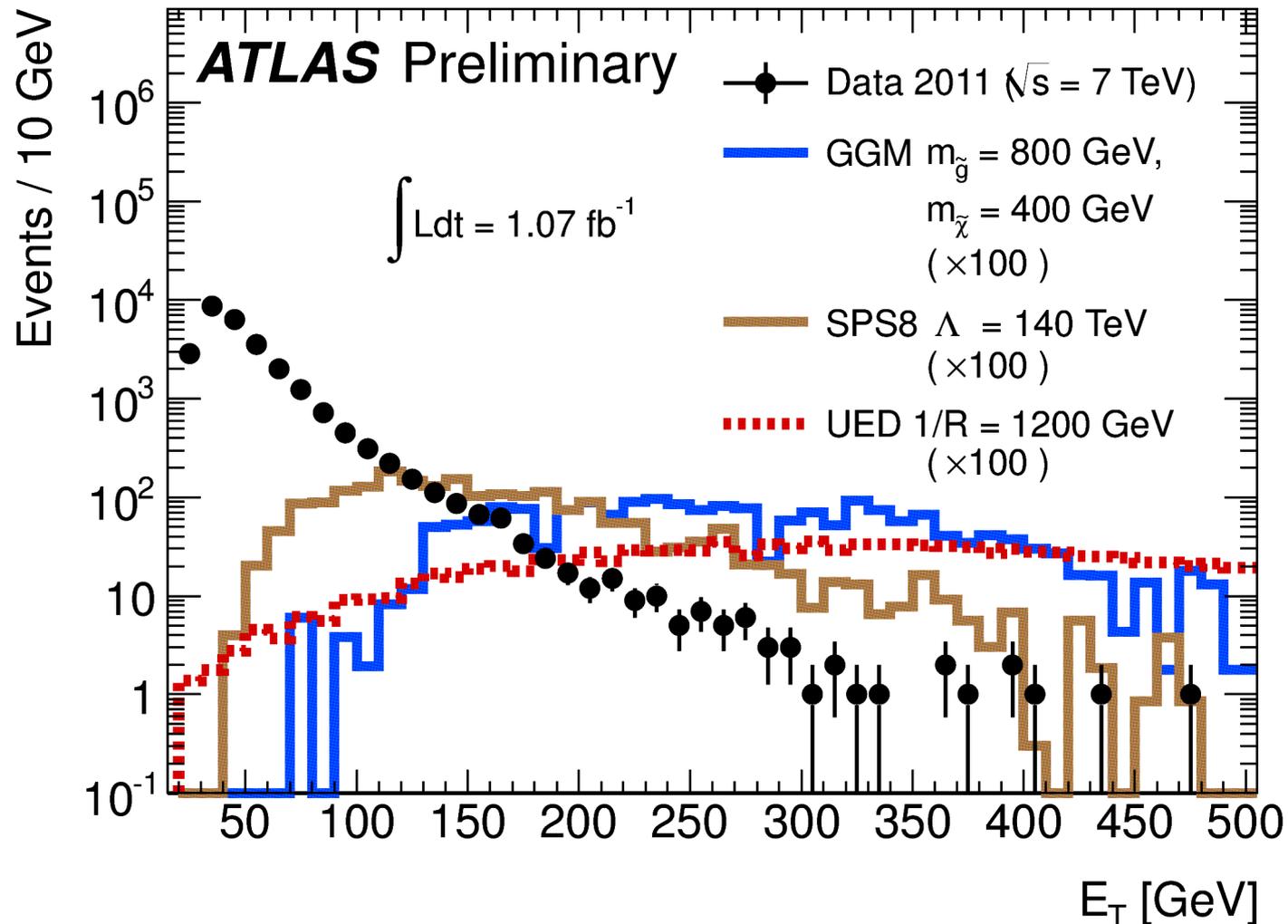
# Event Display

- Candidate signal event
- Photons
  - $E_T$ : 398, 265 GeV
  - $\eta$ : 0.71, 0.49
  - $\phi$ : 1.6, -1.5
- Both photons are in the calorimeter barrel
- $E_T^{\text{miss}} = 302$  GeV (red line image)
- Jets:
  - $E_T$ : 138, 55, 31 GeV
  - $\eta$ : 1.46, 0.87, 2.64,
  - $\phi$ : 0.9, 2.1, 0.9



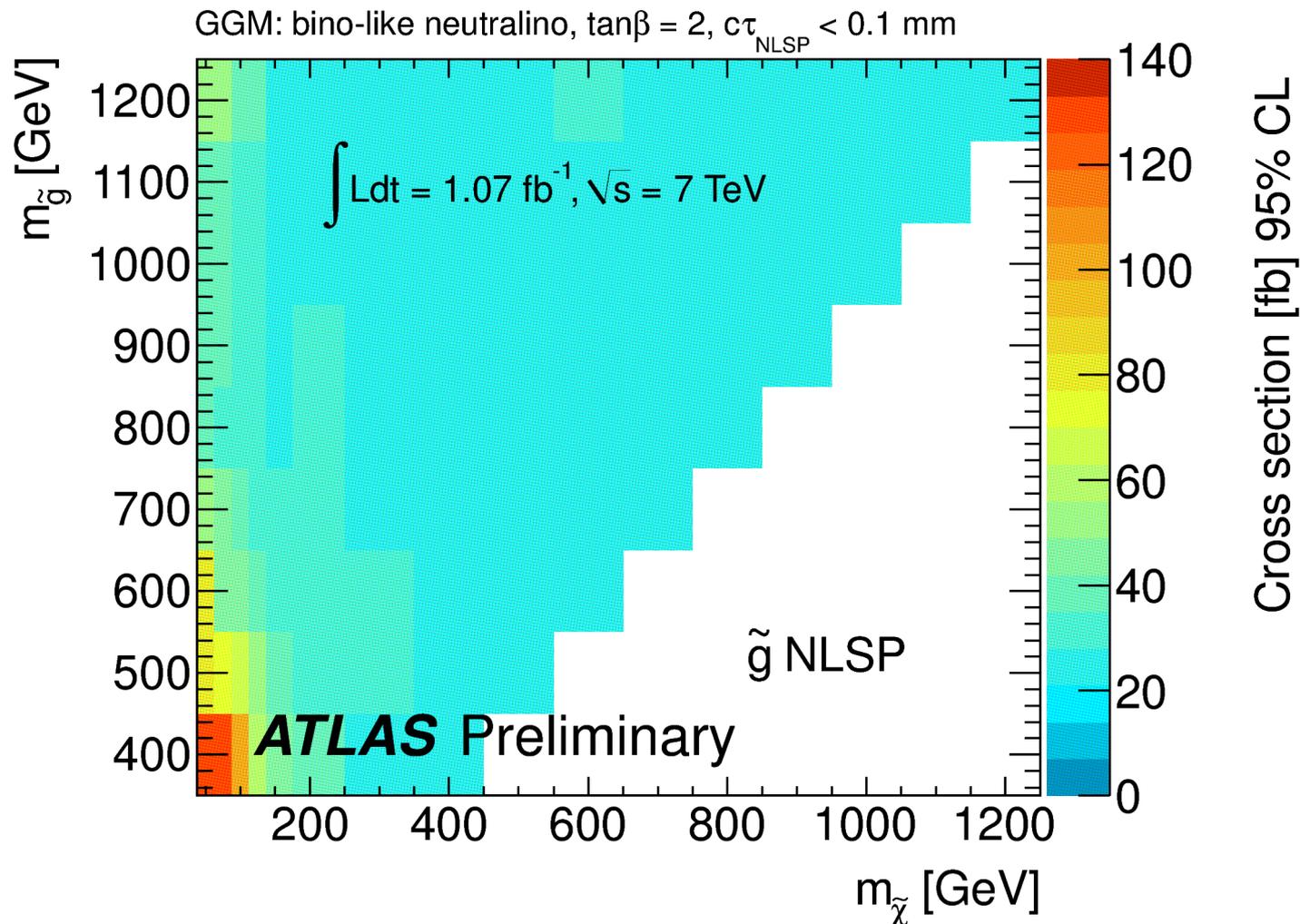
# Photon $P_T$ Spectrum

- The  $E_T$  spectrum of the leading photon in the  $\gamma\gamma$  candidate events



# GGM Cross-Section Limits

- Observed 95% CL upper limit for the GGM production cross section



# Limits – GGM (Enlarged Plot)

- Current ATLAS limit:  $M_{\text{gluino}} > 776 \text{ GeV}$  for  $M_{\text{bino}} > 50 \text{ GeV}$

