ATLAS/CMS Search for SUSY-like Signals in Topologies with Photons

Yuri Gershtein

Outline

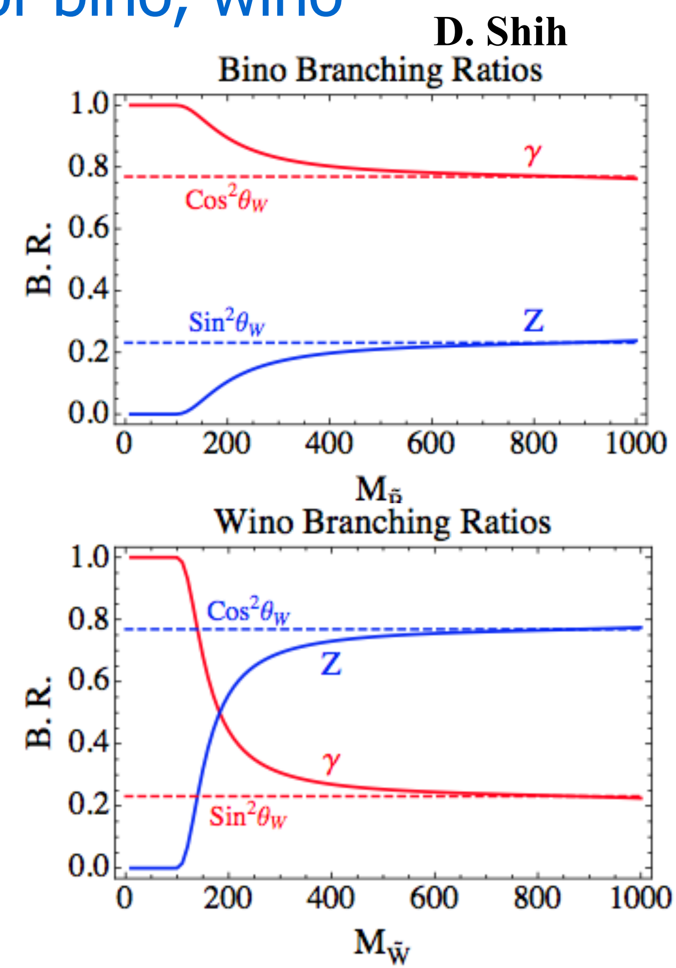
- What kind of SUSY gives signatures with photons
  - neutralino NLSP in General Gauge Mediation
- Experimental results
  - MET + Di-photon (ATLAS + CMS)
  - MET + photon + jets (CMS)
  - MET + photon + lepton (CMS)
- Summary/outlook

Gauge Mediation

- SUSY breaking is mediated by gauge fields ("messengers"), and occurs at scales much smaller then M_{Pl}
  - an elegant solution to SUSY flavor problem
- Makes the gravitino very light and the LSP
- SUSY particles decay into NLSP and then NLSP decays into gravitino
  - NLSP lifetime can be large
- In minimal GM, just two alternatives
  - Slepton NLSP (stau, or co-NLSP if sleptons are mass degenerate)
  - Neutralino NLSP (pure bino) – decays predominantly into photon and gravitino and rarely into Z+gravitino

General Gauge Mediation

- In general case, neutralino is a mixture of bino, wino and higgsino $\left(\tilde{B}^0, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0\right) \rightarrow \left(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0\right)$
- For "pure" cases:
  - Bino -> photons and some Z's
  - Wino -> photons and Z's
  - Higgsino -> either
    - 100% Z+gravitino
    - 100% h+gravitino
    - 50-50 Z/h + gravitino
- Note that if NLSP is pure Wino, then the lightest chargino is also Wino and is mass-degenerate with neutralino
  - Decays directly into W±+gravitino



- Design search strategy with simple benchmark models, but be careful not to miss topologies from mixed neutralinos

GGM Phenomenology

- If R-parity is conserved, all events have two NLSP's

D. Shih, J. Ruderman

channel	bino	wino	Z-higgsino	bino-higgsino mix
$\gamma\gamma + \not{E}_T$	✓			
$\ell\gamma + \not{E}_T$		✓		
jets + $\not{E}_T$		✓	✓	✓
$Z(\ell^+\ell^-) + \text{jets} + \not{E}_T$			✓	
$Z(\ell^+\ell^-)Z(\ell'^+\ell'^-) + \not{E}_T$			✓	
$Z(\ell^+\ell^-)h(b\bar{b}) + \not{E}_T$				✓
$h(b\bar{b})h(b\bar{b}) + \not{E}_T$				✓
$\gamma + h(b\bar{b}) + \not{E}_T$				✓
$\gamma + \text{jets} + \not{E}_T$	✓	✓		✓
$\ell + \text{jets} + \not{E}_T$		✓		

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$h(b\bar{b})h(b\bar{b}) + \not{E}_T$				✓
$\gamma + h(b\bar{b}) + \not{E}_T$				✓
$\gamma + \text{jets} + \not{E}_T$	✓	✓		✓
$\ell + \text{jets} + \not{E}_T$		✓		

Covered in this talk (only prompt NLSP decays)

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$\gamma + \text{jets} + \not{E}_T$	✓	✓		✓
$\ell + \text{jets} + \not{E}_T$		✓		

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CMS/ATLAS search exists

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$h(b\bar{b})h(b\bar{b}) + \not\!\!E_{\mathrm{T}}$				✓
$\gamma + h(b\bar{b}) + \not\!\!E_{\mathrm{T}}$				✓
$\gamma + \text{jets} + \not\!\!E_{\mathrm{T}}$	✓	✓		✓
$\ell + \text{jets} + \not\!\!E_{\mathrm{T}}$		✓		

may discover SUSY & Higgs in one go!

Covered in this talk (only prompt NLSP decays)

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Simplified Models & Interpretation of Results

- ArXiv:1105.2838v1 [hep-ph]
  - [P.000: Y. Gershtein, M. Park, J. Ruderman, D. Shih, S. Thomas, Y. Zhao]
  - http://lhcnewphysics.org/photons/p.000.00.r000
- GGM phenomenology is complex
  - need some benchmark points from phenomenologists
  - need experimentalists to present results in a way that can be re-interpreted without too much effort
- Emerging trend:
  - Come up with an inclusive set of cuts
  - Use simplified models to determine acceptance*efficiency and publish that
  - Publish cross section limits for the large parameter space grid
  - Also publish the mass limits in the simplified models
  - This gives phenomenologists enough information to tune PGS or other parameterized simulation and to derive limits for their pet scenarios (for example Ruderman & Shih, arXiv:1103.6083 and arXiv:1009.1665)
- Concern: how to find balance between having inclusive cuts and optimize for the best exclusion of the toy model?

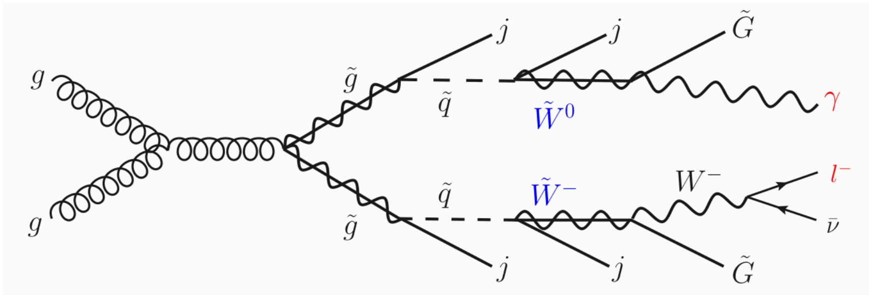
Analyses

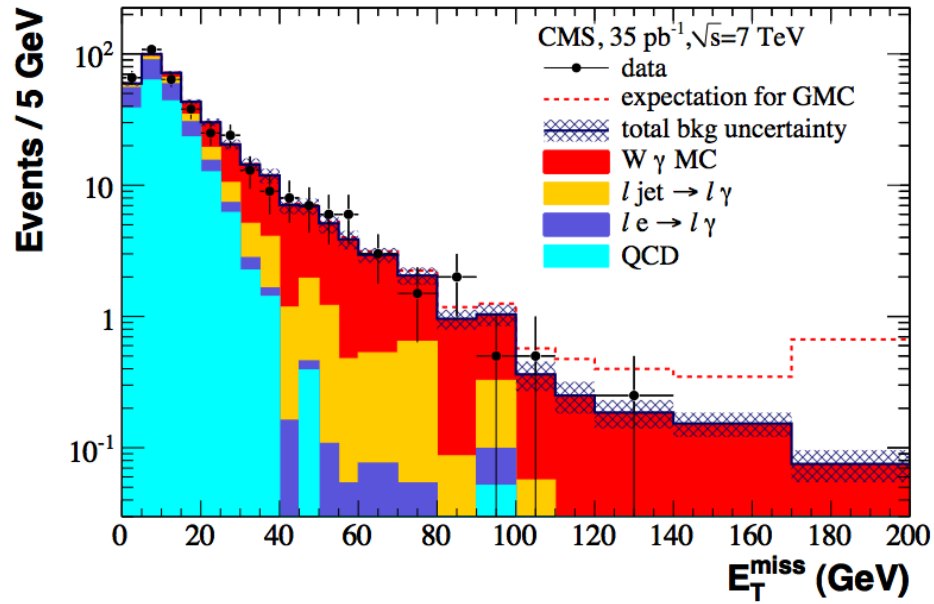
	photons	leptons	jets
$l+\gamma$+MET	≥ 1 $E_T > 30$ GeV $\|\eta\|<1.44$	≥ 1 $E_T > 20$ GeV $\|\eta\|<2.1$	
γ+jets+MET	$=1$ $E_T > 75$ GeV $\|\eta\|<1.44$		≥ 3 $E_T > 30$ GeV $\|\eta\|<2.6$ HT > 400 GeV
$\gamma\gamma$+MET (ATLAS)	≥ 2 $E_T > 25$ GeV $\|\eta\|<1.8$		
$\gamma\gamma$+MET (CMS)	≥ 2 $E_T > 45, 30$ GeV $\|\eta\|<1.44$		≥ 1 $E_T > 30$ GeV $\|\eta\|<2.6$

Backgrounds

	physics	fake photons	QCD
$l+\gamma$+MET	$W+\gamma$ $tt+\gamma$ (neglgible)	W+jet ($j\rightarrow\gamma$) DY, WW, top ($e\rightarrow\gamma$)	$j\rightarrow$lepton
γ+jets+MET	W/Z/top+γ	W, top ($e\rightarrow\gamma$)	QCD γ $j\rightarrow\gamma$
$\gamma\gamma$+MET	W/Z+$\gamma\gamma$ (negligible)	$W\gamma$, top ($e\rightarrow\gamma$)	QCD γ $j\rightarrow\gamma$

Lepton+photon (Wino co-NLSP)

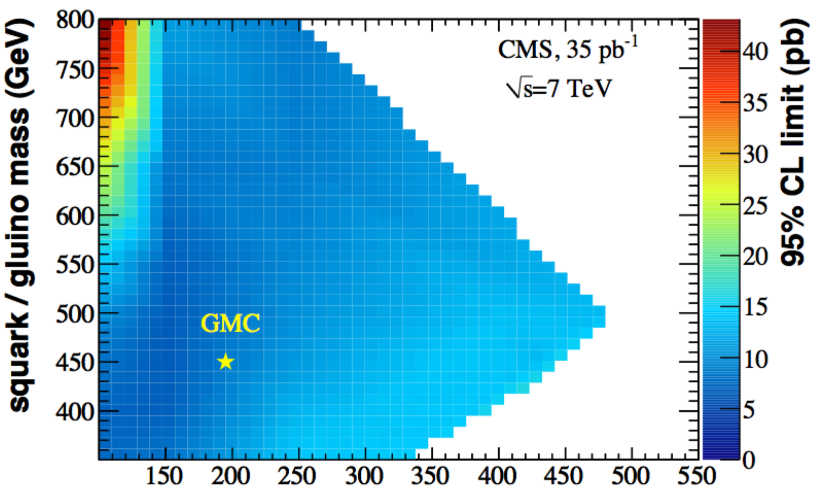


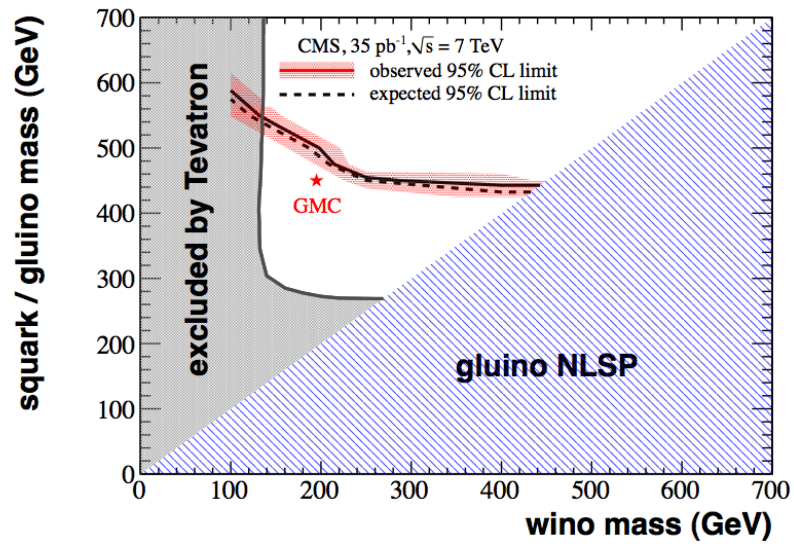


Main background is irreducible Wγ. No NNLO calculation exist, and that may become a problem – how confident are we that NLO gets it right?

Observe 2 events with MET>110 GeV
3.3±0.8 events expected

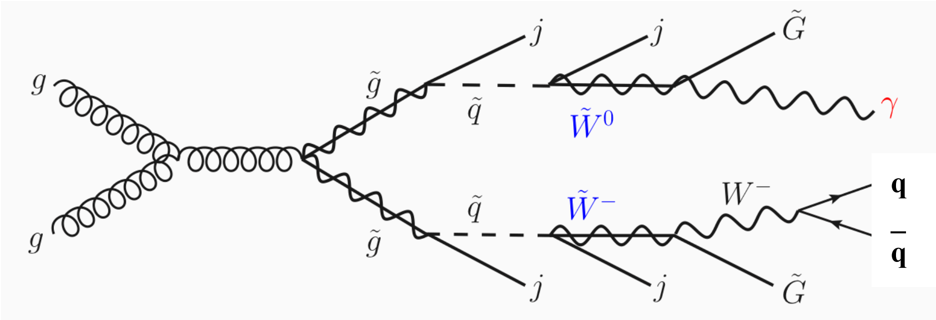
Jet-photon mis-ID is determined from data

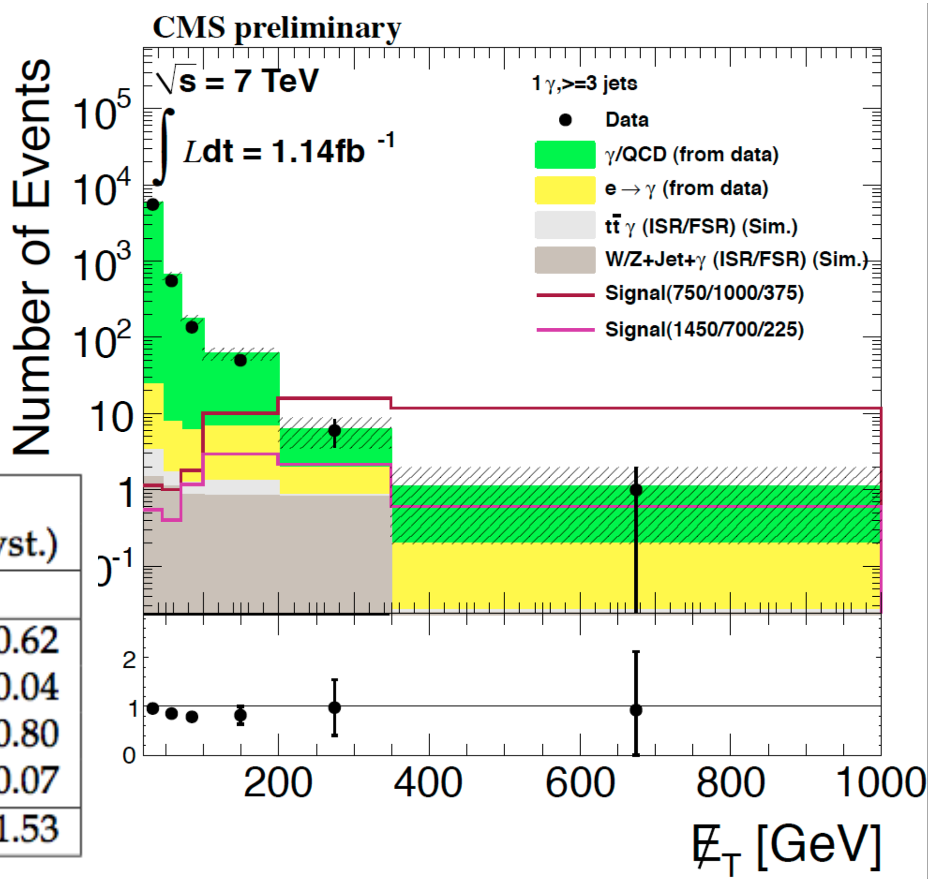




Photon+jets (bino or wino co-NLSP)

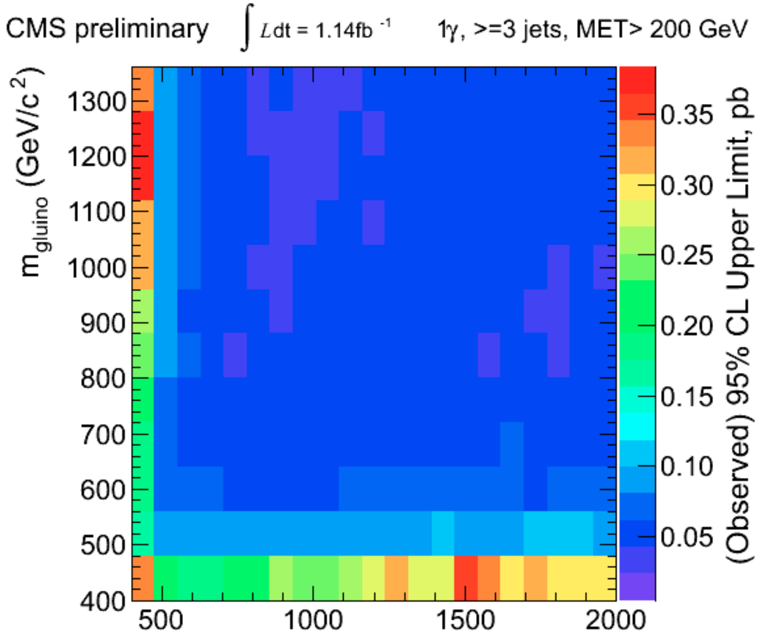
- Irreducible backgrounds are small (W/Z/top + γ)
- QCD with mis-measured MET is the largest – get MET resolution from data using "fake photon" sample
- Electron-photon mis-ID is measured using data (mis-ID rate measured with Z's and applied to electron + jets sample)

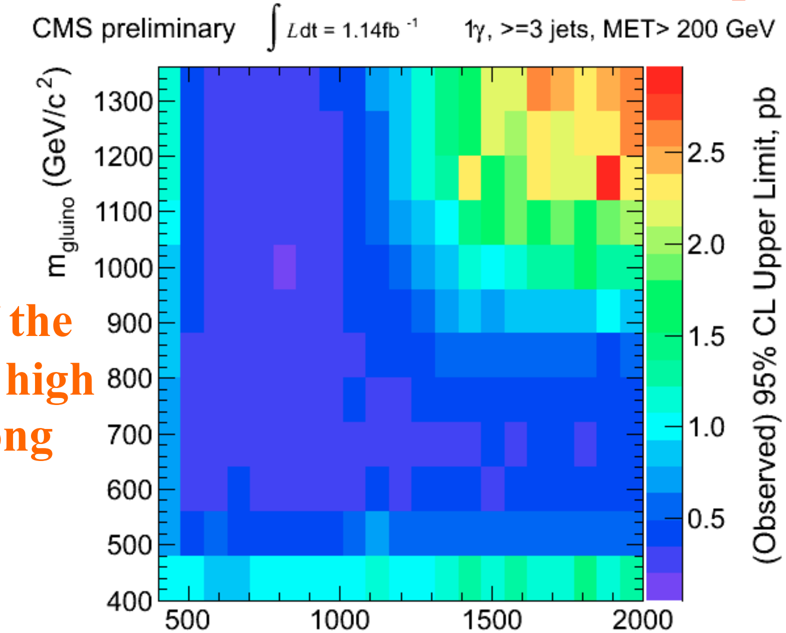




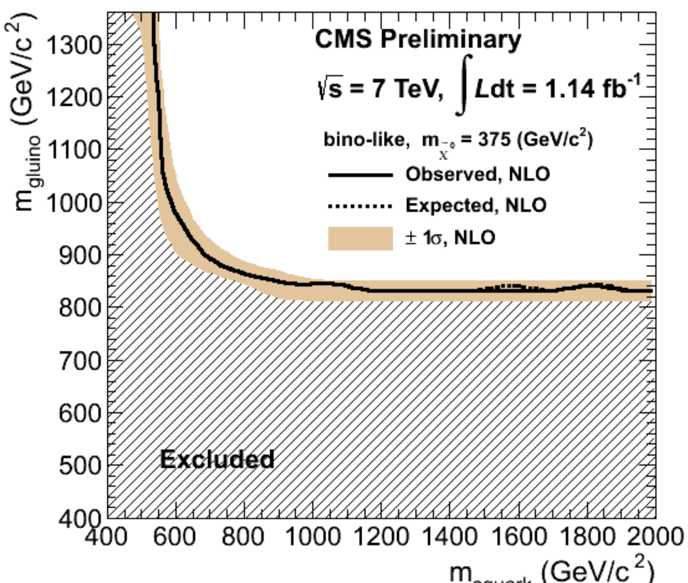
Sample	Event yield	(stat.)	(syst.)
Data	7		
QCD (est. from data)	5.16	±2.58	±0.62
EWK $e \to \gamma$ (est. from data)	1.22	±0.13	±0.04
FSR/ISR ($W \to \mu/\tau\nu, Z \to \nu\nu$) (Sim.)	0.80	±0.31	±0.80
FSR/ISR ($t\bar{t} \to \mu/\tau\nu + X$) (Sim.)	0.07	±0.05	±0.07
Total SM background estimate	7.24	±2.6	±1.53

Photon+jets (bino or wino co-NLSP)



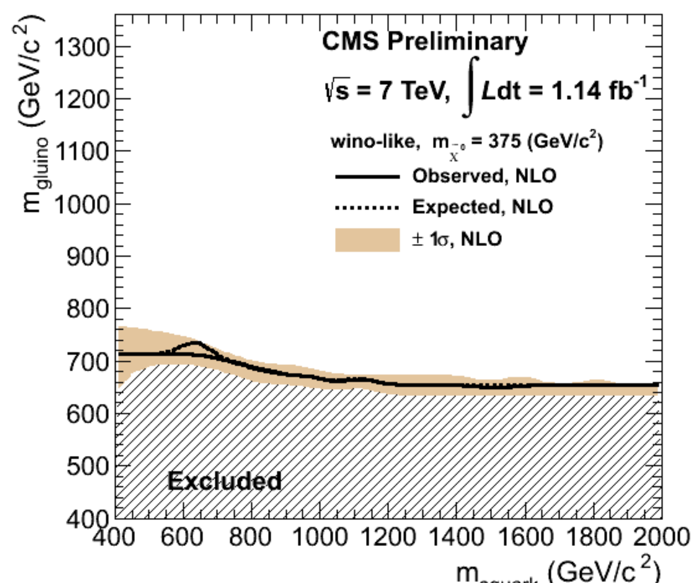


Note the worsening of the wino limit at high masses – strong production switches off

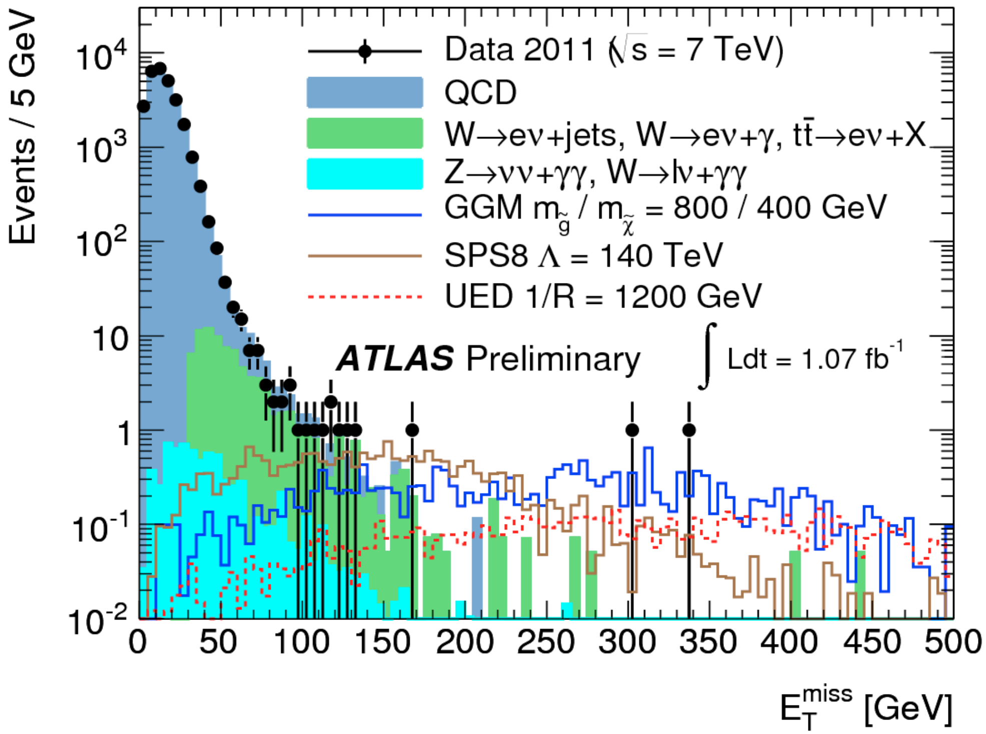


←bino

wino→



Di-photons (Bino)

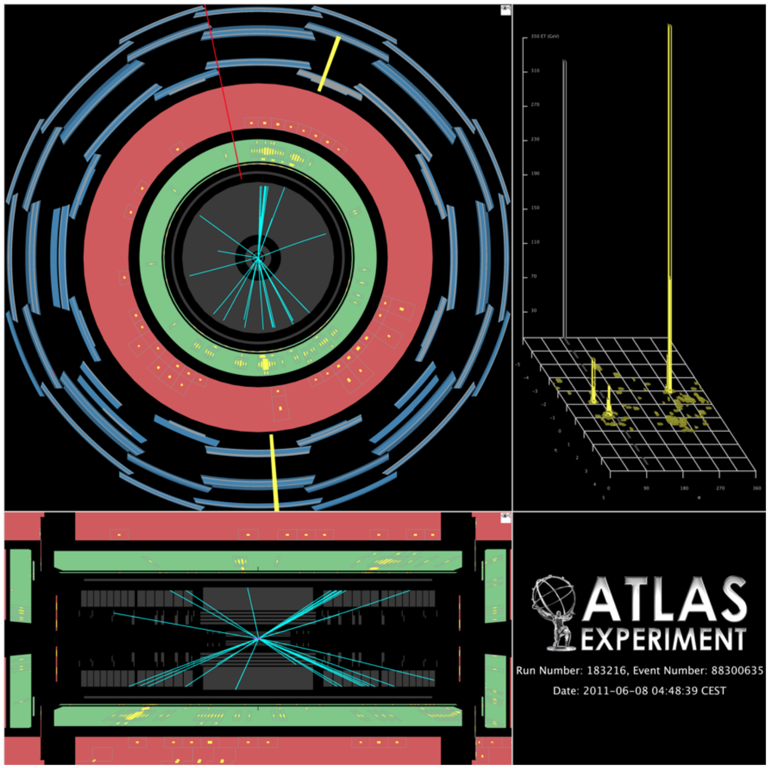


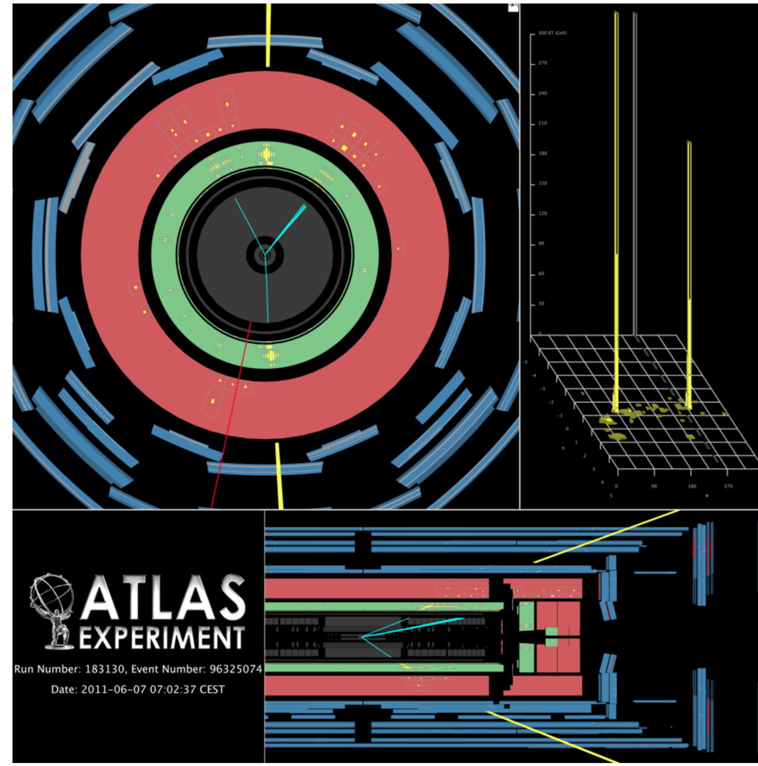
- Irreducible backgrounds are small (Z/Wγγ)
- QCD with MET mis-measurement and EWK with electron-photon mis-identification are both measured with data
- EWK backgrounds dominate at high MET

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

Candidate Events

Two photons (E_T = 432 GeV, and 51 GeV),
Four jets (E_T = 210, 93, 6 and 23 GeV)
MET = 338 GeV

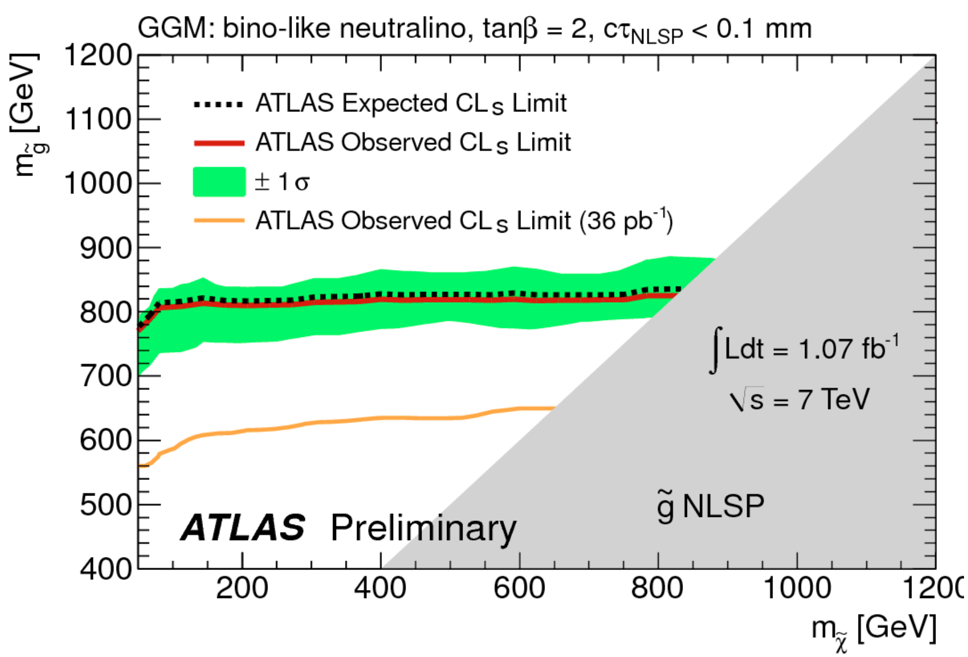


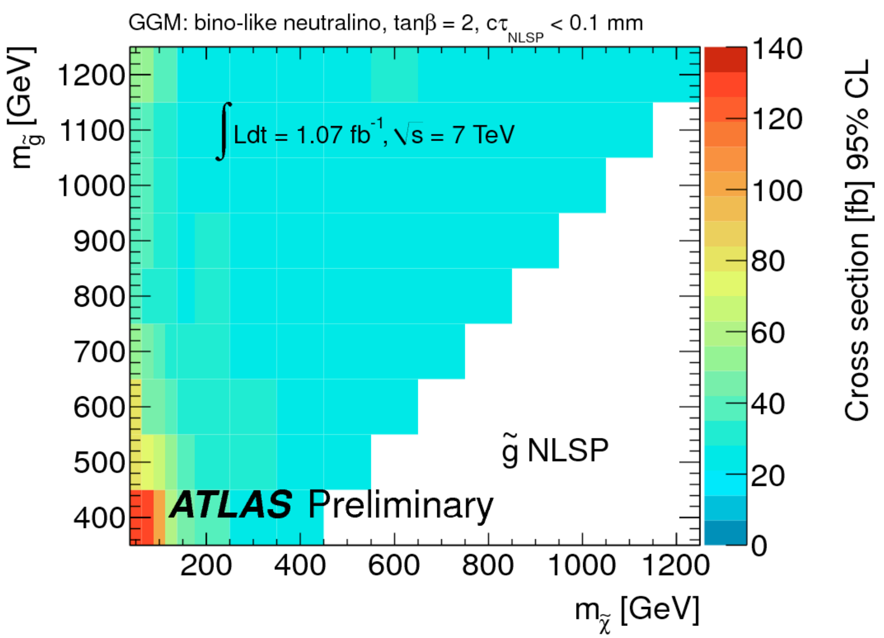


Two photons (E_T = 398 GeV and 265 GeV)
Three jets (E_T = 138, 55, and 31 GeV)
MET = 302 GeV

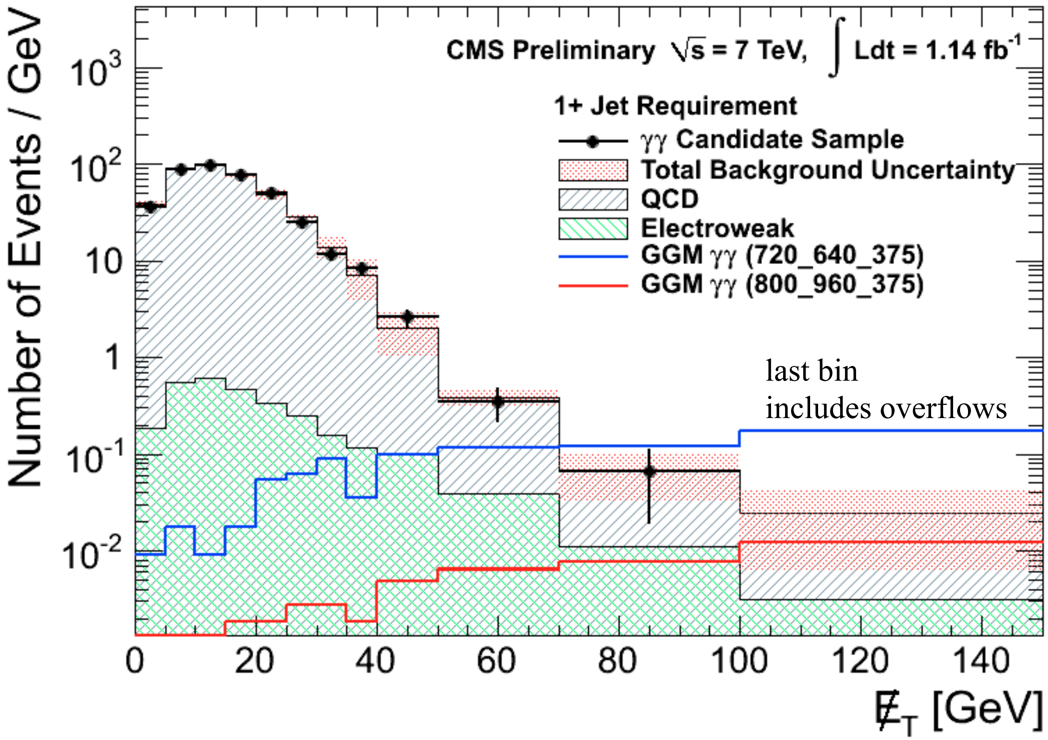
Di-photons (Bino)

- Large improvement w.r.t. 36/pb analysis
- For heavy squarks, gluinos are excluded below ~820 GeV





Di-photons (Bino)

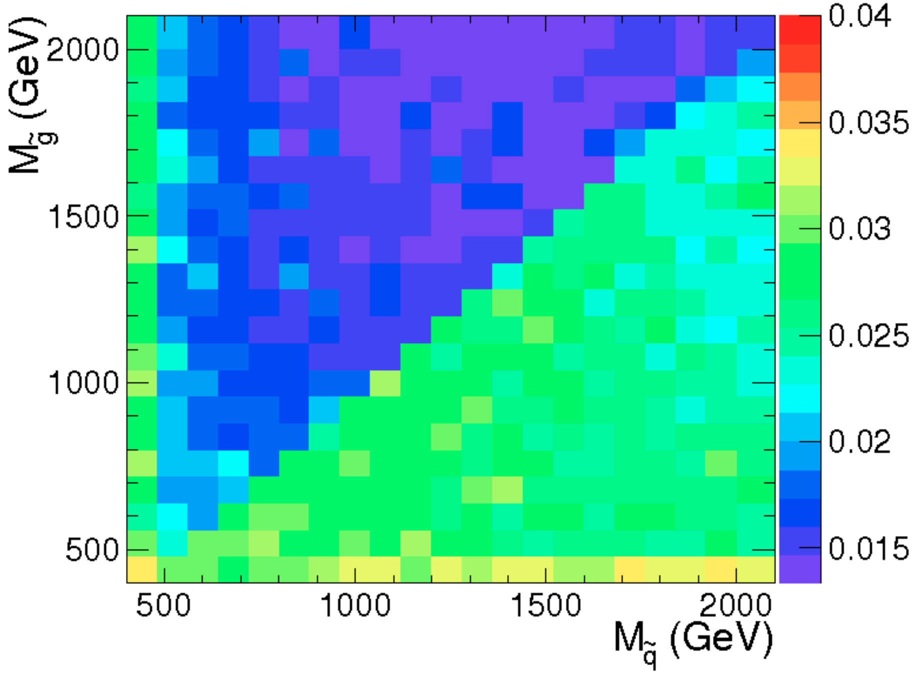


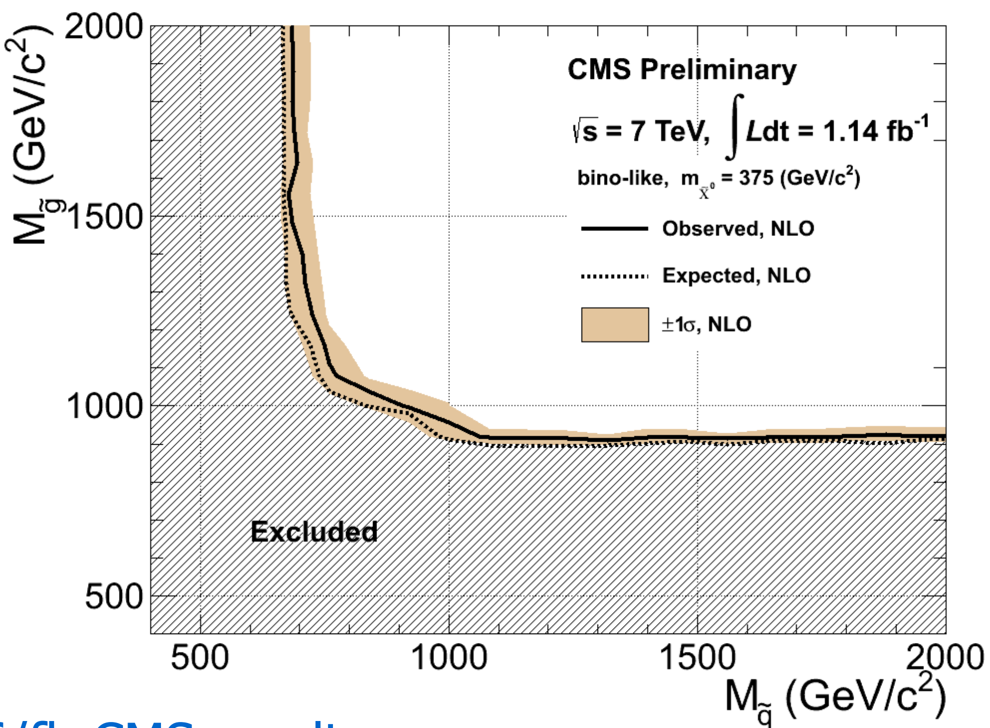
- Very similar to ATLAS analysis
- Higher photon E_T cuts make irreducible backgrounds negligible
- EWK background is smaller compared to QCD, probably owing to smaller $e \to \gamma$ mis-ID probability
  - 1.4% in CMS
  - 5-12% in ATLAS

	MET > 50 GeV	MET > 100 GeV
Observed	9	0
Expected	11.3 ± 2.1	1.5 ± 1.0

Di-photons (Bino)

- Note characteristic jump of excluded cross-sections at M(squark) ~ M(gluino)





- Slightly different model then for 36/fb CMS result
  - Respect GGM sum rules -> if we maximize the number of light degenerate squarks, right-handed Q=2/3 squarks have to be heavy. That reduces the production cross-section

Summary / Outlook

- No SUSY yet
- GGM Neutralino parameter space is pretty well covered
  - γh+MET and Zh+MET are yet to be done
- Next generation of analyses will hit a new level of complexity
  - there are huge number of very rare processes with cross-sections of order 0.1 fb
    - i.e. QED corrections to SM processes
  - double parton scattering
    - σ x Br (WW) →2l (same sign) 0.4 fb
  - details of top production kinematics
    - $\sigma \sim 1.6 \times 10^5$ fb – do we understand its kinematics to 10^{-5}?
  - anomalous jet fragmentation
    - W cross section is 10^8 fb (+30 GeV jet: 10^7 fb) – are we sure we can control subtle jet fragmentation effects to so many orders of magnitude? (q vs. g vs. Q, for instance)
  - Let's hope that SUSY will have striking kinematic features