Searches for SUSY in Events With Photons and Missing Transverse Momentum with the ATLAS Detector

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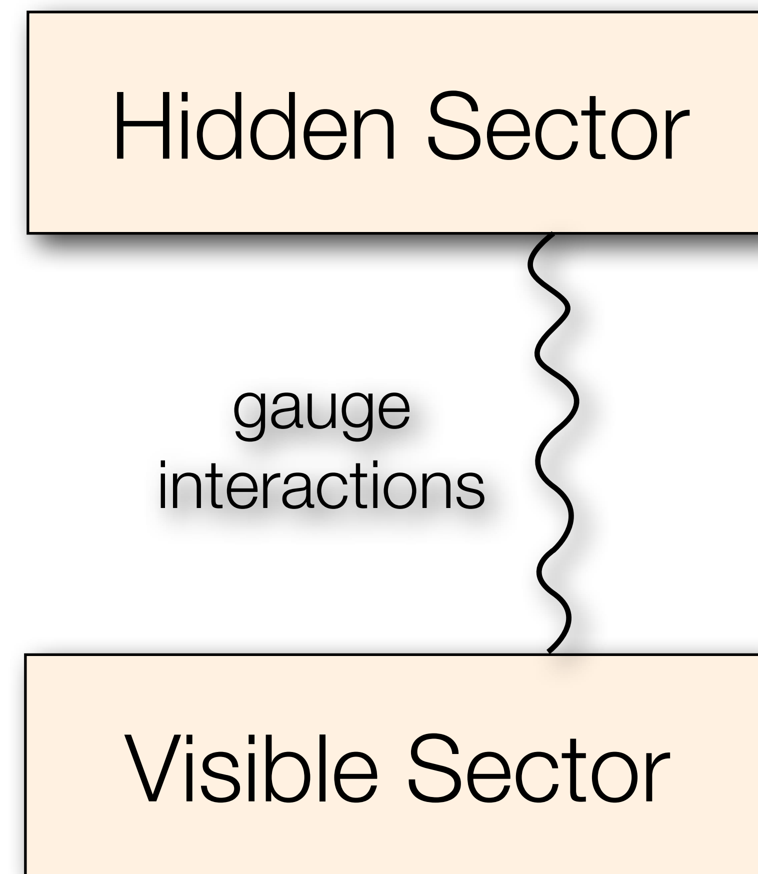
May 3, 2012

Outline

- Introduction to GMSB
- Alternate models (UED)
- The diphoton analysis
  - Event selection
  - Background modeling
  - Signal grids
  - Systematic uncertainties
  - Results and interpretation in the models
- Looking forward: other potential photon searches
- Conclusion

Gauge-Mediated SUSY Breaking (GMSB)

- A hidden sector is responsible for SUSY breaking.
- Standard gauge interactions transmit the SUSY breaking to the MSSM:
  - no flavor problem
- Common Features:
  - Mass scale for the SUSY breaking is much lower than mSUGRA
  - The lightest supersymmetric particle (LSP) is the gravitino
  - The next-to-lightest supersymmetric particle (NLSP), as well as its decay length, determine the experimental signature.



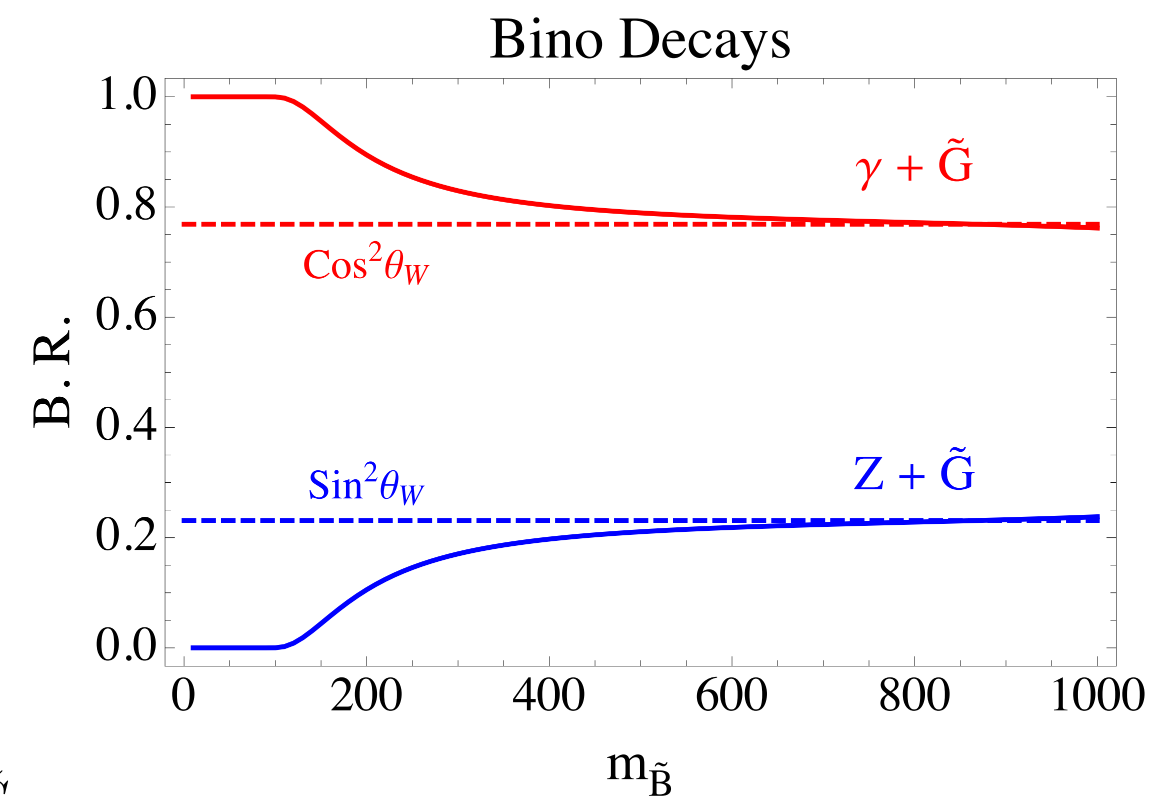
Minimal and General Gauge Mediation

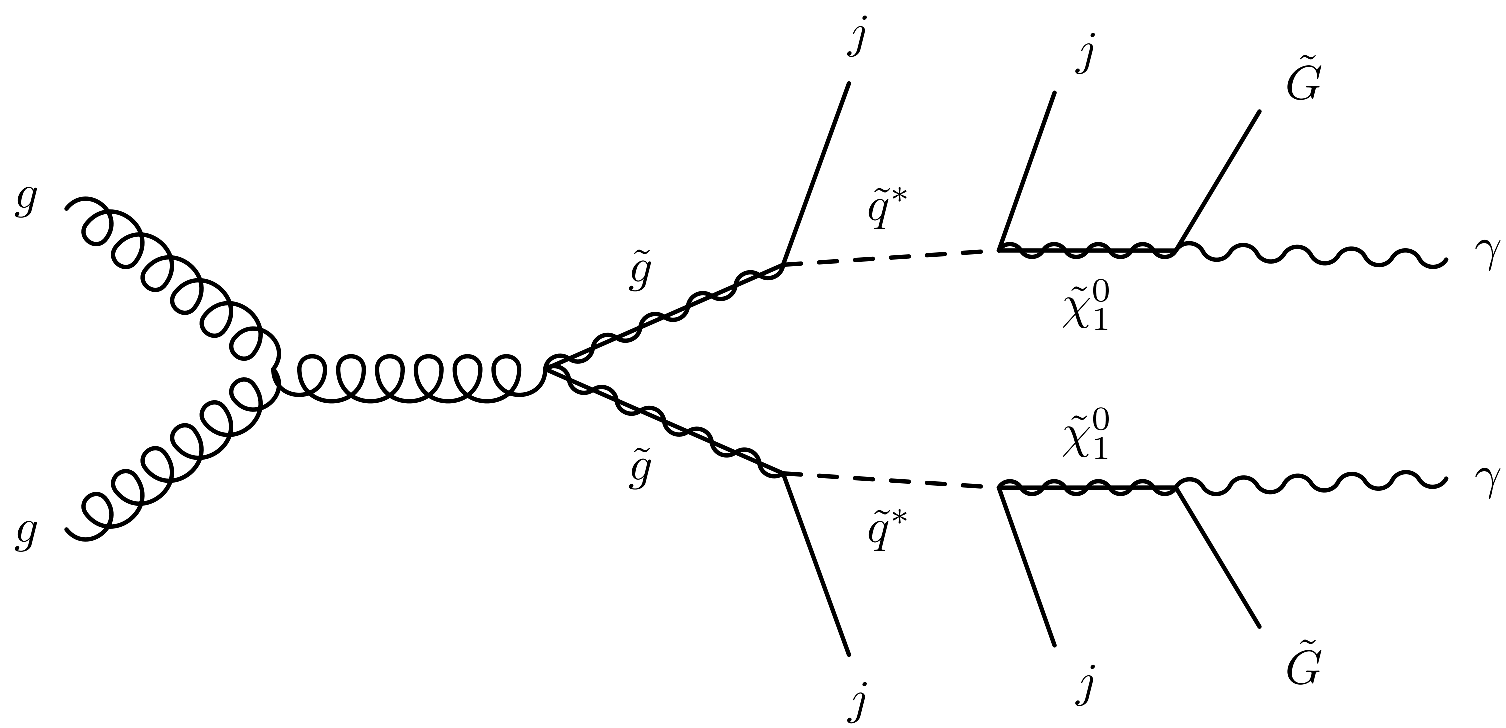
- Minimal Gauge Mediation (MGM):
  - Simple model with one mass scale for the symmetry breaking (Λ) and messengers of mass M_{mess} consisting of N_5 copies of the $\mathbf{5+\bar{5}}$ representation of SU(5).
  - Snowmass SPS 8 is an example with one set of messengers arXiv:hep-ph/0202233v1
  - Gluinos much heavier than neutralinos because $M_a = \frac{\alpha_a}{4\pi}\Lambda N_5.$
- General Gauge Mediation (GGM):
  - Main principle: if the gauge coupling strength were to go to zero, then the SUSY breaking sector and the MSSM sector would decouple [Prog.Theor.Phys.Suppl. 177 (2009) 143-158].
  - The MGM mass hierarchy between gauginos is not required.

Bino NLSP

plot from arXiv:1103.6083v1 [hep-ph]
Joshua T. Ruderman and David Shih

- If $|M_1| << \mu$ and $|M_1| < |M2|$, the lightest neutralino is bino-like.
- Assuming *R*-parity, two sparticles are produced, which cascade down to the bino NLSPs
- The bino decays to a photon or a *Z* + gravitino (we study the photon case)

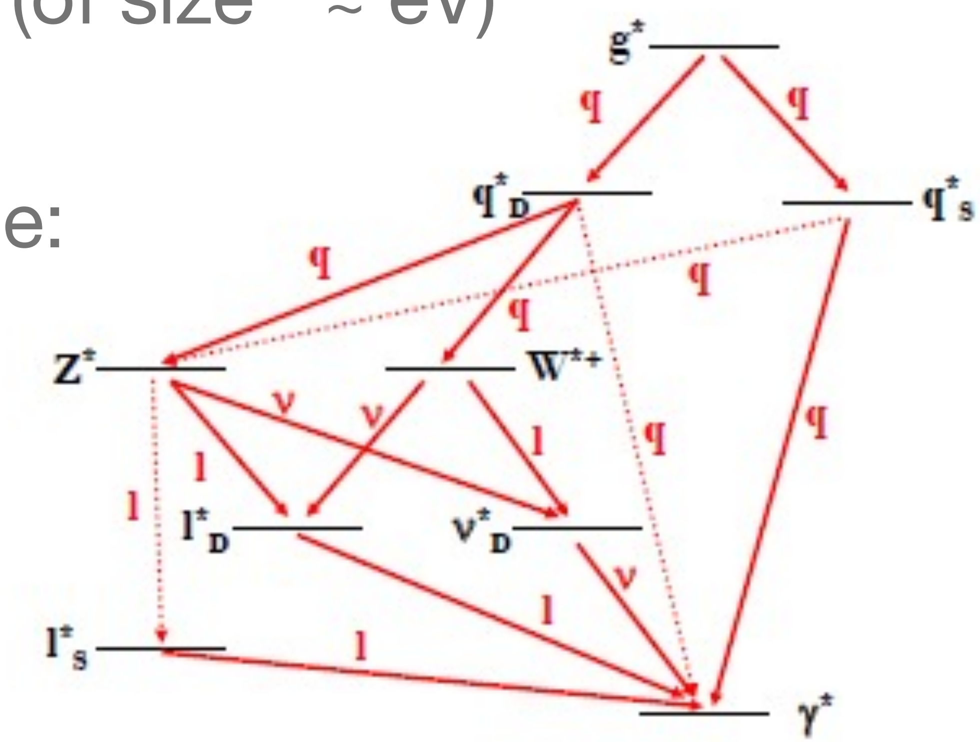




Signature: **two high p_T photons + E_T^{miss}**

Introduction to Universal Extra Dimensions (UED) with One Extra Dimension

- **Universal**: ALL SM particles propagate into the extra dimensions with compactification scale R (1/R ~ 1 TeV)
- quark and gluon KK excitations are pair produced, and cascade decay down to Lightest KK Particle: γ^*
- If the "thick brane", where the SM particles propagate, is embedded in a larger space of (4+N)-dim (of size^{-1} ~ eV) where only gravitons propagate:
  - gravity mediated decays become possible: $\gamma^* \rightarrow \gamma$ + Graviton
- Signature: **two high p_T photons + E_T^{miss}**



The Diphoton Analysis: Bino NLSP using 1.07 fb^{-1} of data from 2011

Published in: Physics Letters B 710 (2012) 519–537

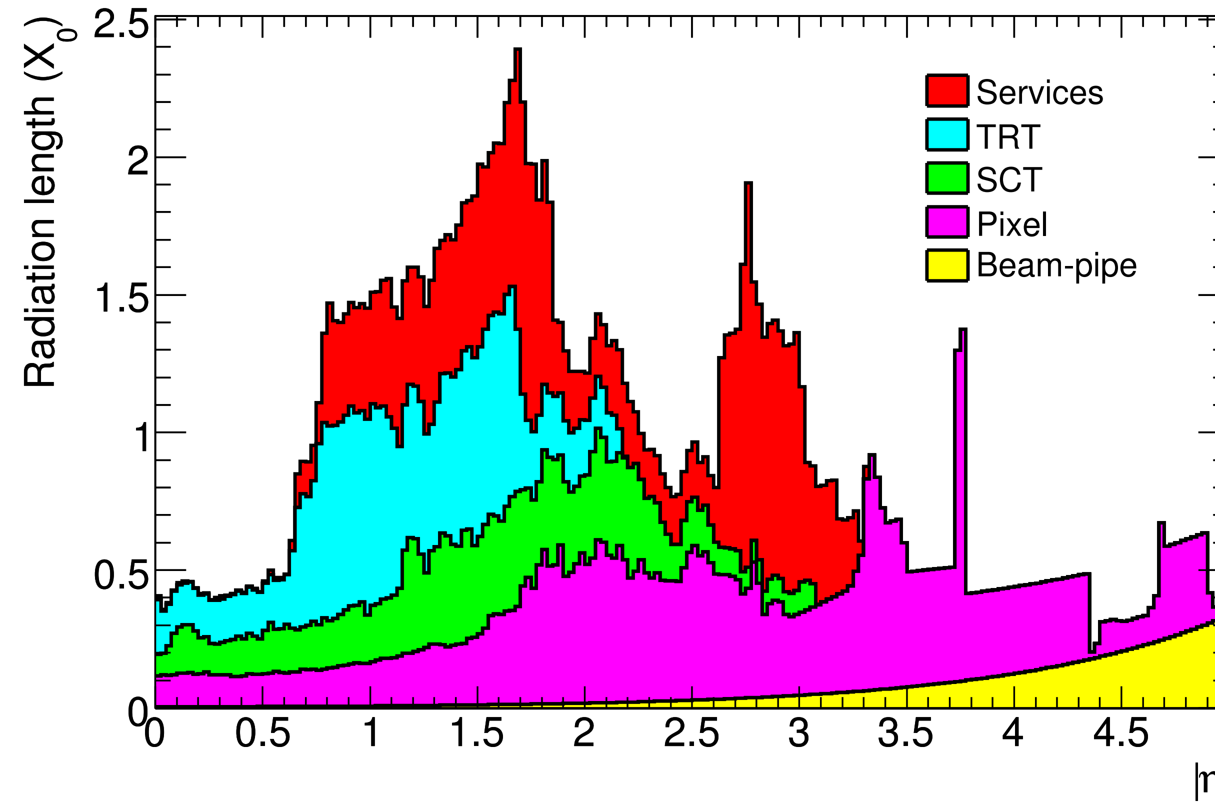
Builds on 36 pb^{-1} analysis with 2010 data:
Eur. Phys. J. C (2011) 71:1744

Selection Criteria for the Summer 2011 Analysis: 1.07 fb^{-1}

- Trigger: 2 loose egamma objects, $p_T > 20$ GeV
- Require two tight photons
  - $p_T > 25$ GeV
  - $|\eta| < 1.81$ but not in the crack region, $1.37 < |\eta| < 1.52$
  - Calorimeter iso: E_T (R < 0.2, excluding core) < 5 GeV
    - corrected for energy leakage outside of core and pileup.
  - Not touching a problematic calorimeter area
- $E_T^{miss} > 125$ GeV, based on local-calibrated topoclusters + muons
- primary vertex with > 4 tracks
- Reject events with:
  - *bad* jets likely from noise, spikes, cosmics, beam background
  - photons that fail LAr cleaning or timing, or electrons that fail timing.
  - selected muon with $|z_0| > 1$ mm or $|d_0| > 0.2$ mm wrt PV

Aside: Discriminating Photons From Electrons

- Due to the many radiation lengths in front of the calorimeter, a large fraction of the photons convert.
- Requiring photons to have no tracks significantly lowers efficiency
- Solution: reconstruct conversions:
  - 2-track conversion: two tracks with electron-like transition radiation, consistent with coming from a massless particle
  - 1-track conversion: one track with electron-like transition radiation, with missing hits in initial live layers.
- Ambiguity resolution heuristic to choose electron/photon interpretation



Background Modeling

- Most background is modeled from from data
- Only model E_T^{miss} distribution
(inspired by similar searches at D0: [doi:10.1103/PhysRevLett.105.221802])
- **Instrumental E_T^{miss} background:** di-γ, γ+jets, dijets
    - model using "QCD" data samples, normalized to γγ in $E_T^{miss} < 20$ GeV
- **Genuine E_T^{miss} background:**
    - electron faking photon: W+γ, W+jets, ttbar
        - model using eγ data sample, scaled by (e → γ fake rate)/(e efficiency)
    - irreducible: Z + γγ, W + γγ
        - from MC, scaled to NLO.
- **Cosmic background:** found to be negligible to signal

The QCD Control Sample

- Model SM γ-jets, dijets, and diphoton using a QCD control sample
- **pseudo-photon**: a photon that passes loose but fails some tight criteria
- Define QCD control sample:
  - Require two egamma objects with $p_T > 20$ GeV at trigger
  - **at least one pseudo-photon**
  - Veto events with medium electrons or with two tight photons
  - Apply LAr calorimeter timing cut on pseudo-photons to suppress cosmics ($|\Delta t| > 10$ ns: veto event)
- Normalized in $E_T^{miss} < 20$ GeV range: **0.8 ± 0.3 (stat)**

Systematics to the QCD Modeling

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- **Normalization systematics:**
  - Normalize the QCD control sample to the data sample in various 10 GeV subranges of E_T^{miss}: 0-10 GeV, 1-11 GeV, ... 18-28 GeV
  - Assign a **2.8%** error to the normalization

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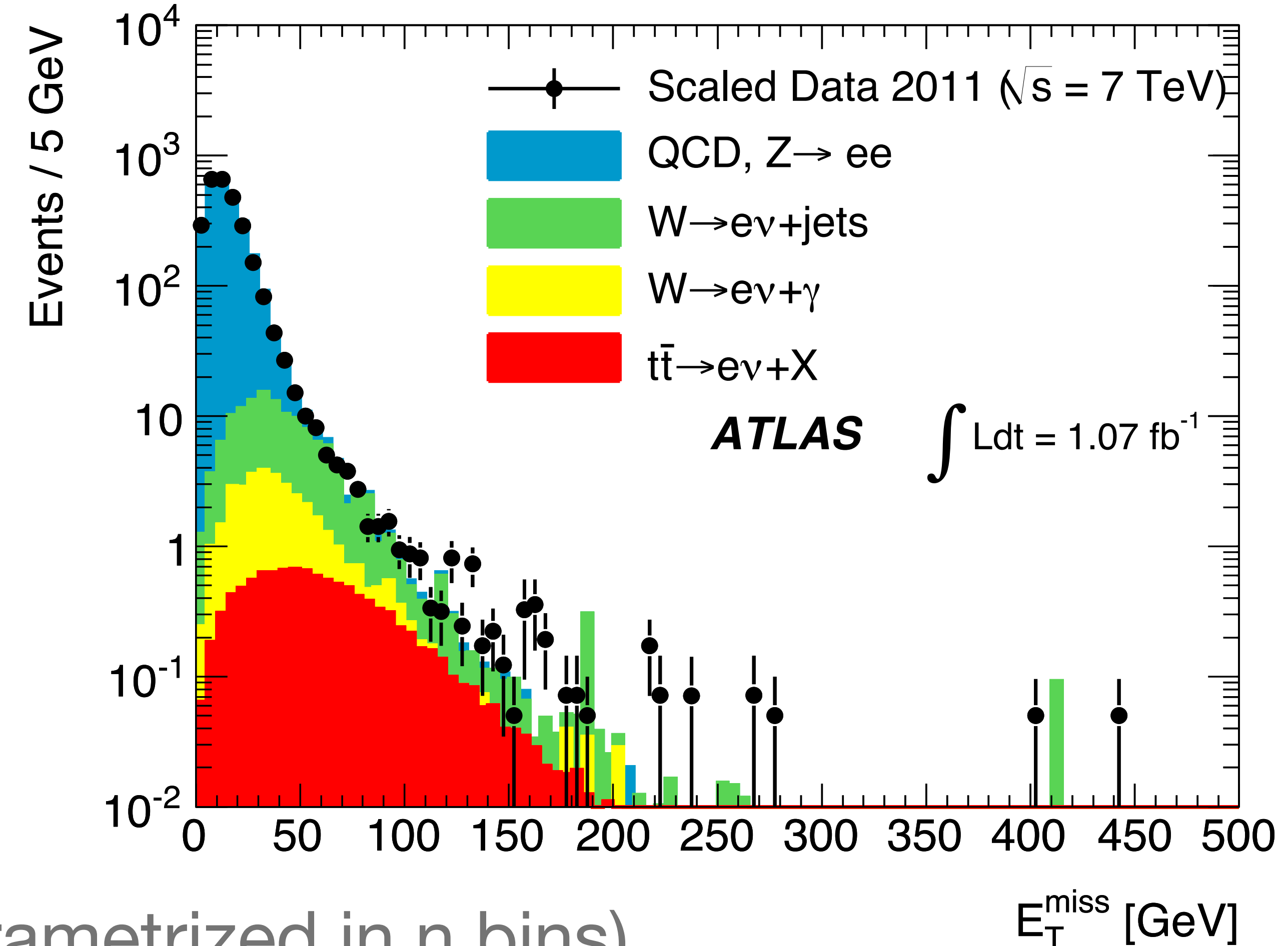
- **Composition systematic:**
  - The QCD control sample models both samples where there is a jet faking a photon and SM diphoton samples.
  - The calorimeter response to jets and photons differs, so the E_T^{miss} should also differ.
  - $Z \rightarrow ee$ (0 jets) were found to model SM diphoton events well in MC.
  - Therefore, substitute a dielectron data sample (0 jets) with a *Z* window cut for QCD sample.
  - Assign a systematic of **± 0.6 events** to the predicted contribution.

Real E_T^{miss} Background: W+γ, W+jets, ttbar

- Use eγ events from data.
  - Assumption: electron fakes a photon.
- Need to subtract out the *Z* and QCD contribution to avoid double-counting.
  - Use QCD sample normalized to eγ in $E_T^{miss} < 20$ GeV,
- Scale the sample by the e→γ fake rate / electron efficiency (~6% in barrel, 17% in endcaps, parametrized in η bins).
  - The scale factor was measured in data: *Z* tag and probe.
- Predicted background: **3.1 ± 0.5 (stat)**

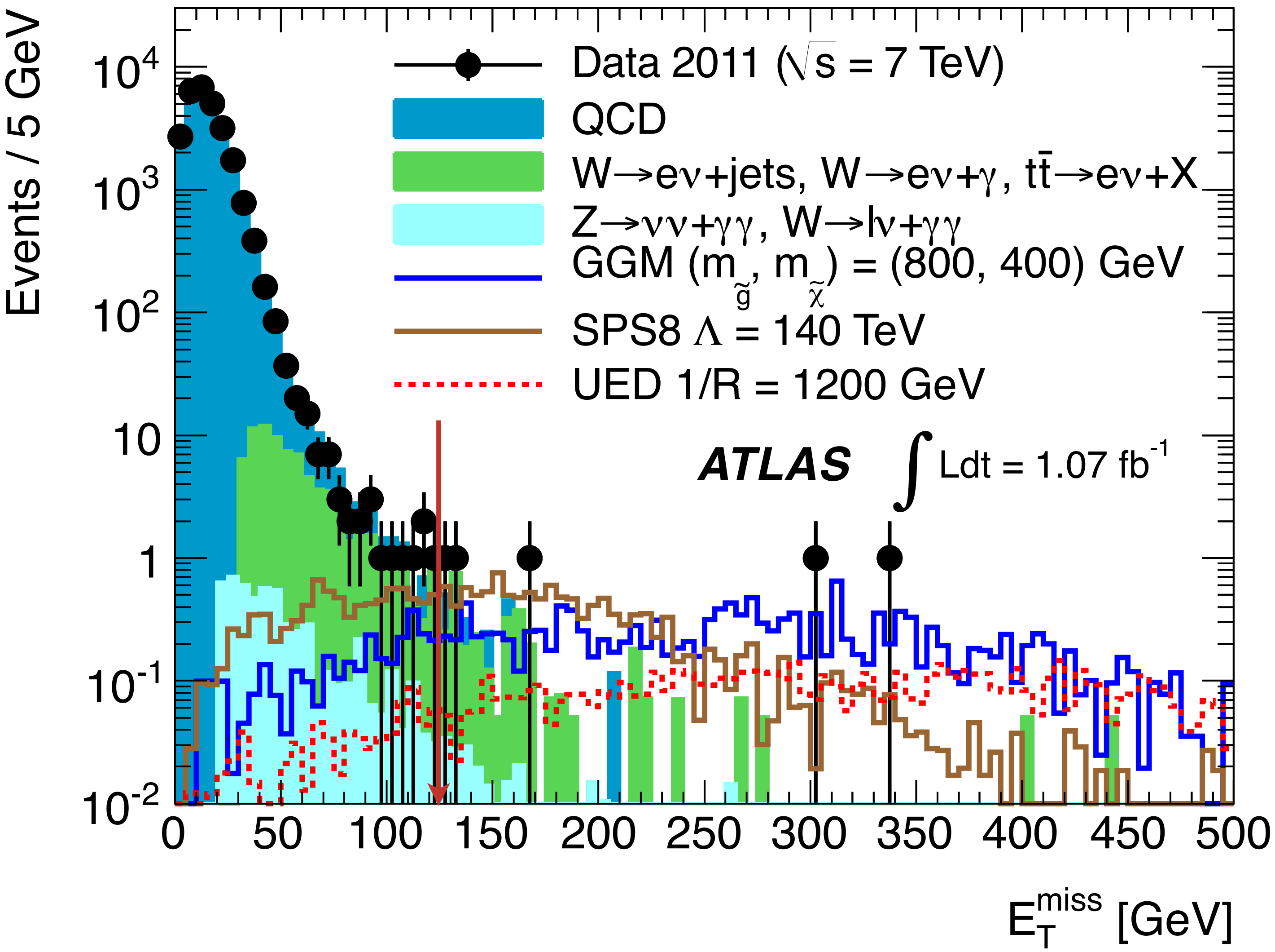
electron-photon sample



Systematics to the W+γ, W+jets, ttbar Modeling

- Uncertainty in the e→γ fake rate / electron efficiency scale factor: **10%**
- Instead of using the QCD sample to model QCD and *Z* contamination in the eγ control sample, use a dielectron data sample with a Z mass window requirement: systematic of **± 0.06 events.**
- Compare the prediction using the eγ control sample to that of MC:
  - normalized the MC to the eγ control sample for E_T^{miss} > 40 GeV range
  - systematic to the background prediction: **± 1.41 events.**
  - Also vary the E_T^{miss} normalization range: negligible.

The Experimental Results



In signal region (E_T^{miss} > 125 GeV)

Total predicted background:

4.1 ± 0.6(stat) ± 1.6(syst) events

Total observed:

5 events

Model-independent CL$_s$ limit:

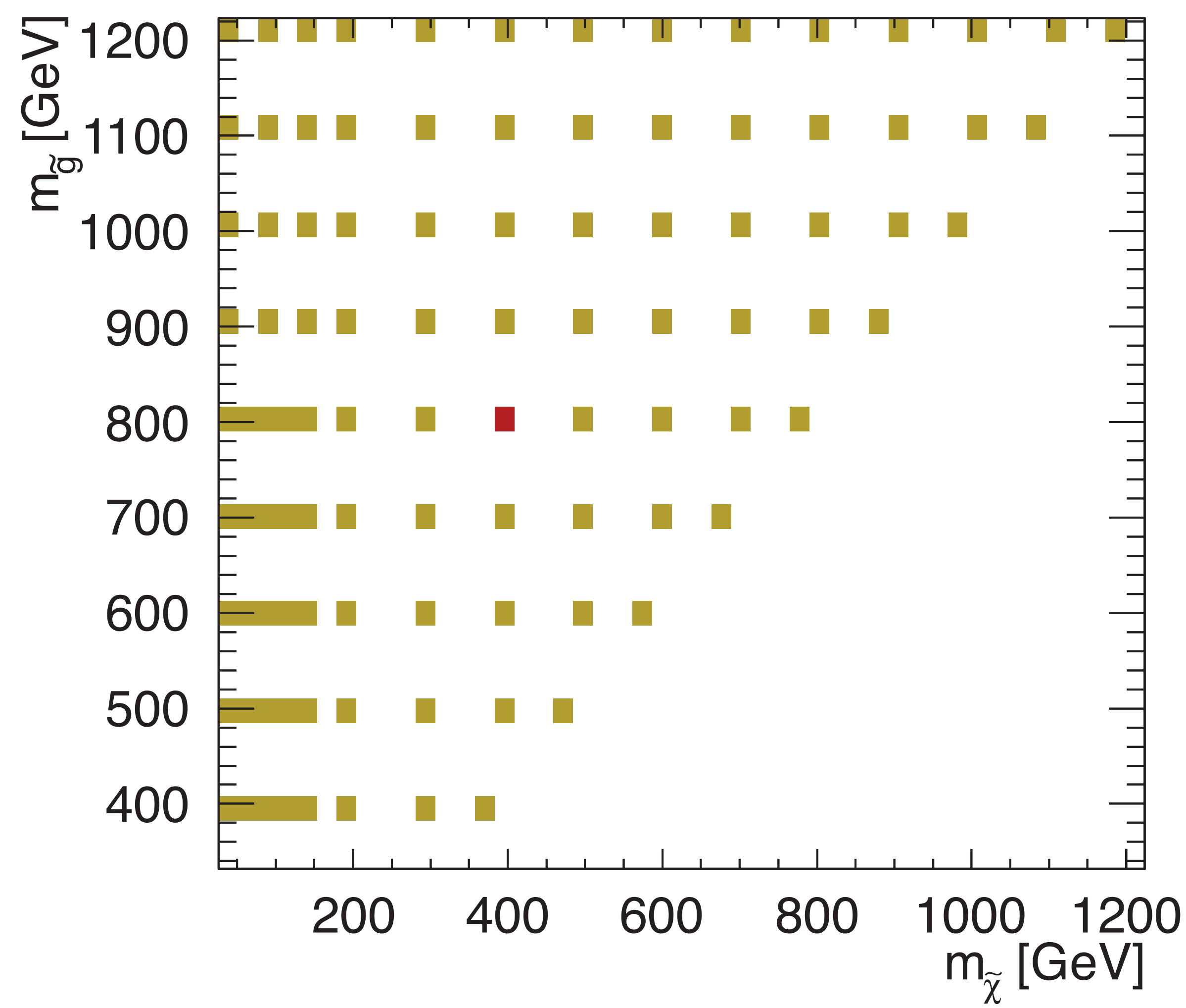
7.1 events

Statistical uncertainties only

E_T^{miss} range [GeV]	Data events	Predicted background events				Expected signal events		
		Total	QCD	$W/t\bar{t}(\to e\nu)+X$	Irreducible	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	3.55 ± 0.35	0.45 ± 0.08	1.53 ± 0.10	0.11 ± 0.01
50 - 75	86	87.1 ± 3.3	60.9 ± 2.8	25.2 ± 1.7	1.01 ± 0.16	0.48 ± 0.08	2.19 ± 0.12	0.14 ± 0.01
75 - 100	11	14.7 ± 1.2	6.7 ± 0.9	7.4 ± 0.8	0.52 ± 0.10	0.75 ± 0.10	2.09 ± 0.11	0.15 ± 0.01
100 - 125	6	4.9 ± 0.7	1.6 ± 0.4	3.0 ± 0.5	0.32 ± 0.08	1.20 ± 0.12	2.53 ± 0.13	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	12.98 ± 0.28	9.67 ± 0.11

GGM Signal Samples

- Created a 2D grid in gluino and bino-like neutralino mass for GGM
- In the *simplified model* style, the gluino production is meant to be a placeholder for any strong production.
- Turn off squark production.
- M_2 = 1.5 TeV, μ = 1.5 TeV, $\tan\beta$ = 2
- $c\tau_{NLSP}$ = 0.1 mm
  (allowed to increase somewhat in low bino mass extension, but < 1 mm)
- All soft parameters are set to 1.5 TeV
- Go down to a bino mass of 50 GeV
- Use SUSPECT, SDECAY, and PYTHIA for event generation
- Use Prospino 2.1 for cross section calculation.



Snowmass SPS8: (arXiv:hep-ph/0202233v1)

- Snowmass SPS8: minimal GMSB (MGM) with
  - $N_5 = 1$, $\tan\beta = 15$, $\mu > 0$, $M_{mess}/\Lambda = 2$
  - Λ varies in steps of 10 TeV in the range 50 - 250 TeV
  - Use ISAJET for mass spectrum and decay table, then Herwig++ for generation.
  - Cross sections calculated with Prospino. K-factors are 1.1 – 1.5
- In the mass range we are setting limits, SPS8 is dominated by weak production.

Λ[TeV	σ(LO)[pb]	σ(NLO)[pb]	K factor
50	12.2	18.0	1.482
60	4.38	6.49	1.482
70	1.83	2.69	1.468
80	0.855	1.24	1.446
90	0.436	0.617	1.415
100	0.240	0.331	1.379
110	0.141	0.189	1.341
120	0.0867	0.113	1.302
130	0.0557	0.0707	1.271
140	0.0370	0.0459	1.241
150	0.0252	0.0306	1.215
160	0.0176	0.0210	1.190
170	0.0125	0.0146	1.172
180	8.99×10^{-3}	0.0104	1.158
190	6.57×10^{-3}	7.49×10^{-3}	1.141
200	4.83×10^{-3}	5.47×10^{-3}	1.131
210	3.58×10^{-3}	4.02×10^{-3}	1.123
220	2.68×10^{-3}	2.99×10^{-3}	1.114
230	2.02×10^{-3}	2.23×10^{-3}	1.107
240	1.53×10^{-3}	1.68×10^{-3}	1.100
250	1.16×10^{-3}	1.27×10^{-3}	1.096

UED Grid Points

- A UED grid was simulated at various 1/R values, and the following parameters:
  - $\Lambda R = 20$, $N = 6$, $M_D = 5$ TeV
- Note that the to photon branching ratio goes down as 1/R goes up: particles start decaying gravitationally directly instead of always going to a γ^* first.

Signal $1/R$ [GeV]	Cross section [pb]	$\gamma\gamma$ B.R.
1000	0.133	100%
1100	0.0521	95%
1200	0.0205	90%
1250	0.0129	83%
1300	0.00803	75%
1350	0.00498	67%
1400	0.00312	60%
1500	0.00120	50%

Systematics

- PDF errors are estimated by weighting 44 error PDFs from CTEQ6.6m and using the Hessian method
- Scale: factorization and renormal-ization scale ×2, ×1/2
- Photon ID/Iso: systematics related to data/MC differences and correction.
  - Also includes extra material
- E_T^{miss}: due to topocluster energy scale and resolution uncertainties.
- Pileup uncertainty by varying MC pileup configuration

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%
Pile-up	1.3%	1.3%	1.6%
E_T^{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%

<u>Representative points:</u>

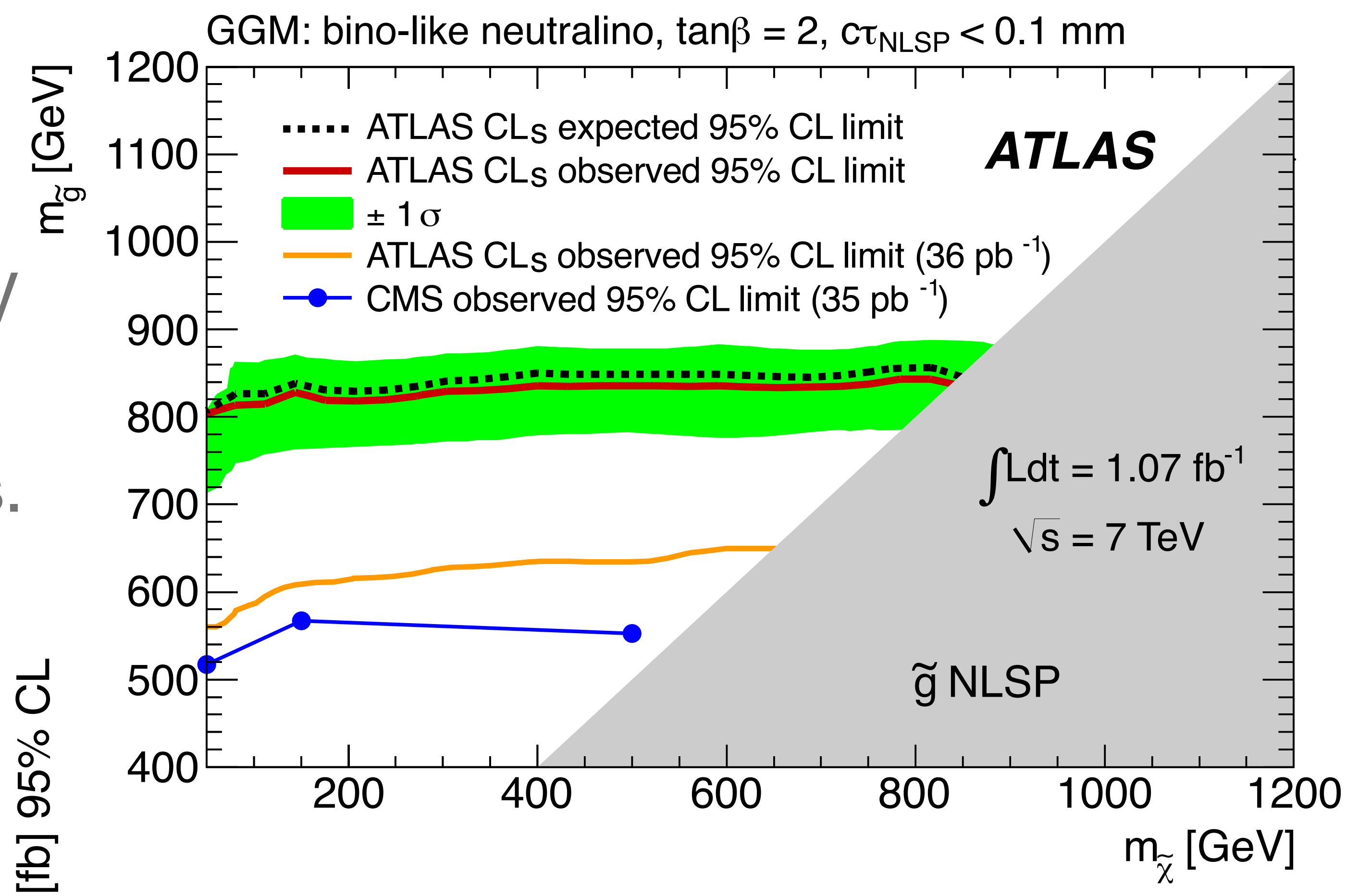
GGM with $m_{gluino}/m_{neutralino}$ = 800/400 GeV

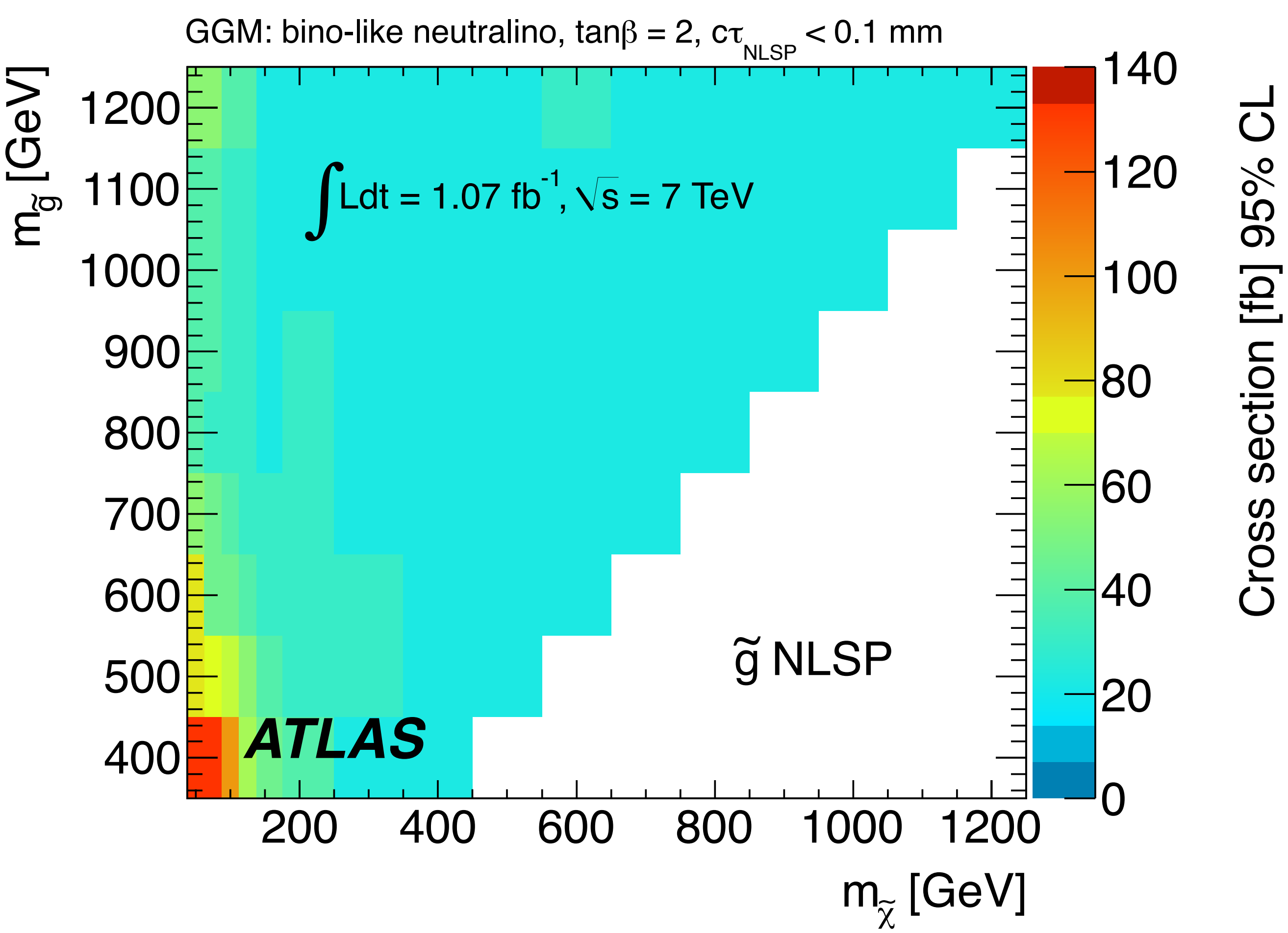
SPS8 with Λ = 140 TeV

UED with 1/R = 1200 GeV

GGM Results

- We use CL_s
- $\sigma < 22 - 129$ fb for GGM model
  - $\sigma < 30$ fb when $m_{bino} \geq 150$ GeV
  - Can be used to give ideas for models with similar parameters.



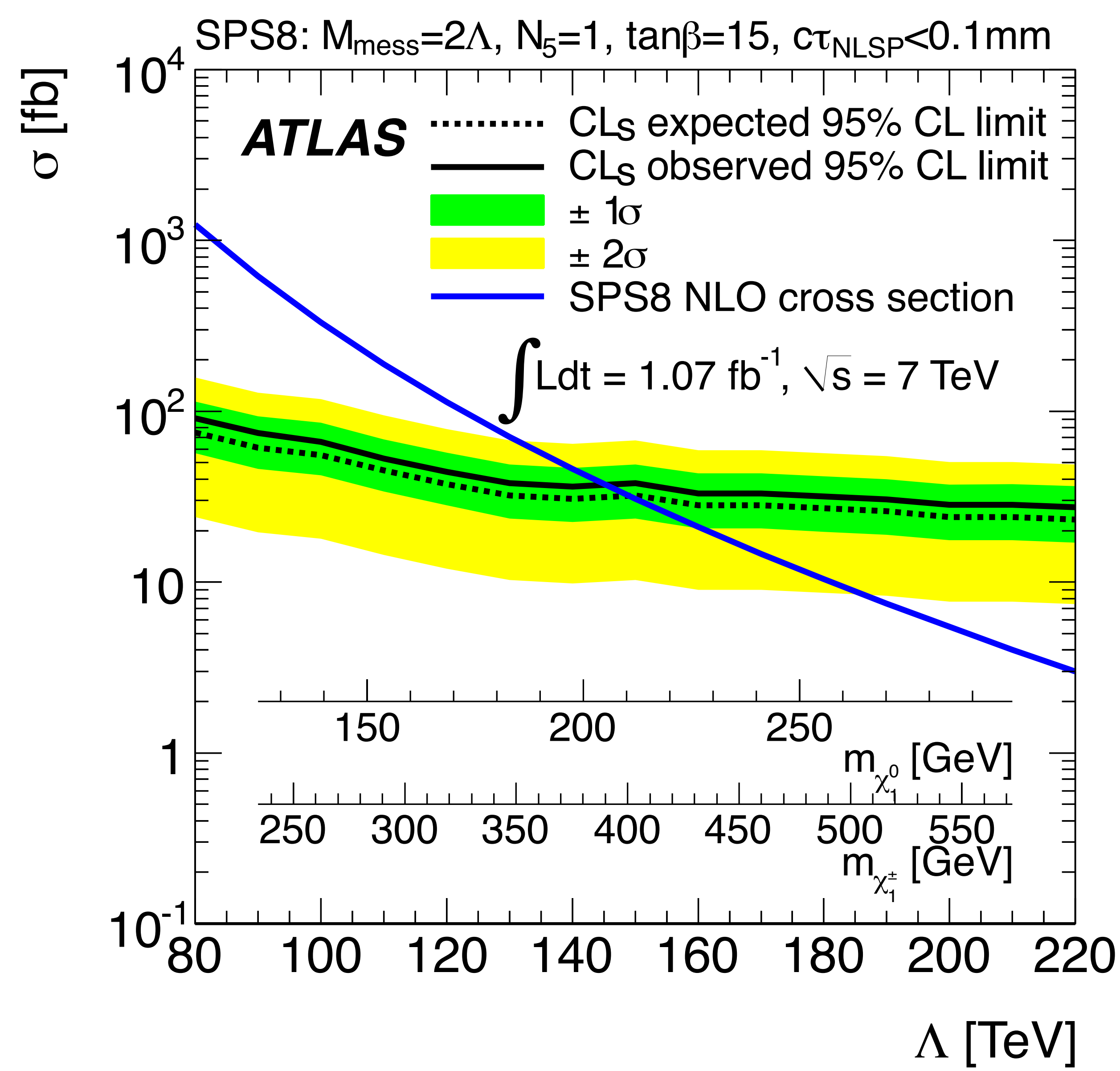


$m_{gluino} > 805$ GeV

for $m_{bino} > 50$ GeV

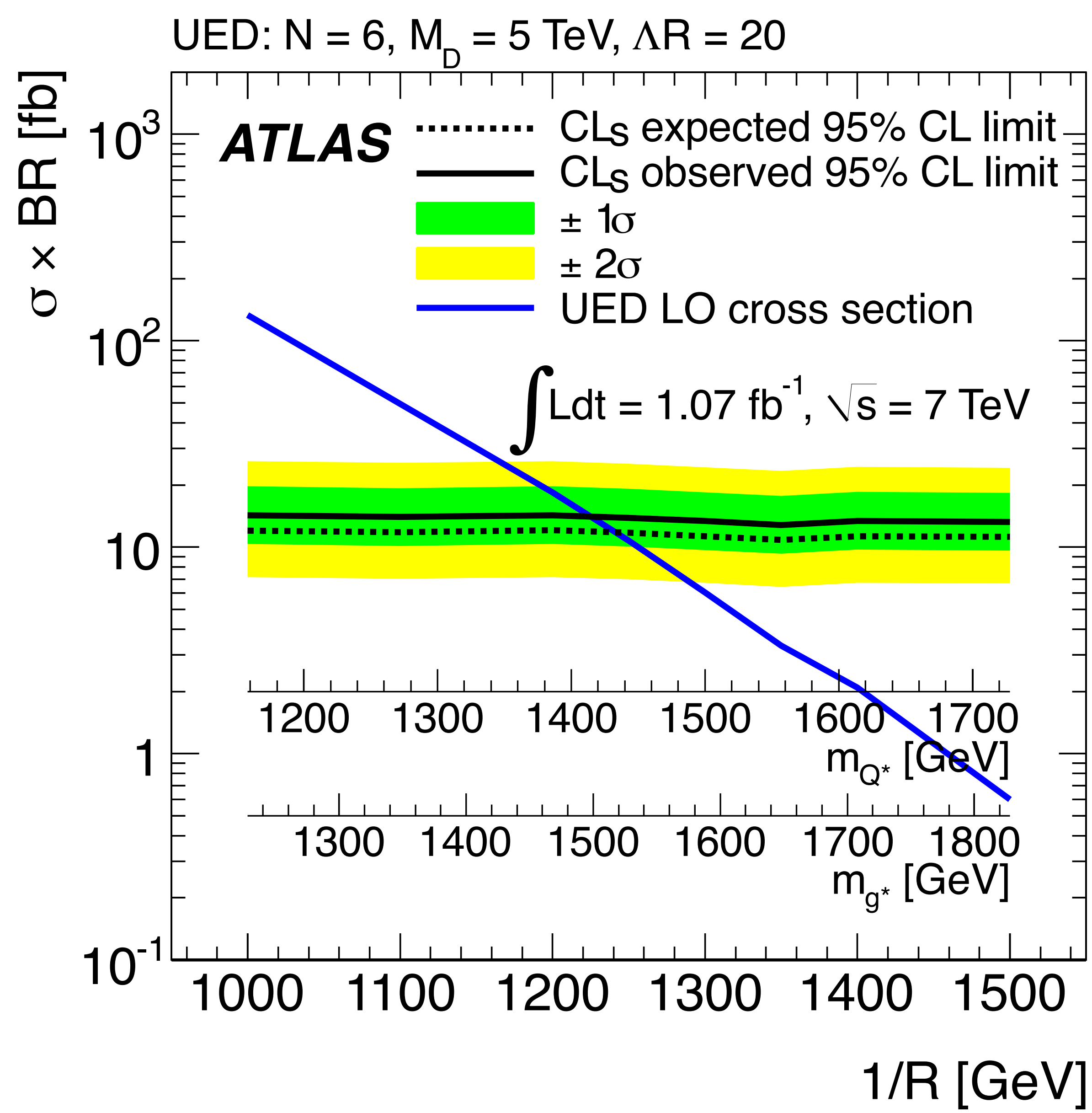
SPS8 Benchmark Result

- Using CLs
- **Λ > 145 TeV** at 95% CL (Λ > 150 TeV expected)
- D0 has set a limit of Λ > 124 TeV (arXiv:1008.2133v1)
- σ < 27 – 91 fb
- This is mostly probing electroweak production
- Best current limit.



UED Result and Statistical Interpretation

- CL_s is used
- Model specific limit:
  1/R > 1.23 TeV at 95% CL
  (1/R > 1.24 TeV expected)
- Cross section limit:
  σ < 15 – 27 fb
- Previous ATLAS limit:
  1/R < 961 GeV
  [arXiv:1107.0561v2 [hep-ex]]



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- Model-independent limit: 7.1 events.
- Results are interpreted for GGM and SPS8 with a bino-like NLSP, and for UED models:
  - GGM: $M_{gluino} > 805$ GeV for $M_{bino} > 50$ GeV
  - SPS8: $\Lambda > 145$ TeV
  - UED: $1/R > 1.23$ TeV

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- Electrons faking photons are the main background. Now with more data, we can afford to tighten it up. We are looking at:
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- Different grid points have different features:
  - In the GGM grid, the gluino and bino can be close in mass: event has few extra objects (jets) but has large photon p_T and E_T^{miss}.
  - In the GGM grid, the bino mass can be low: the event has limited photon p_T and E_T^{miss}, but energetic jets
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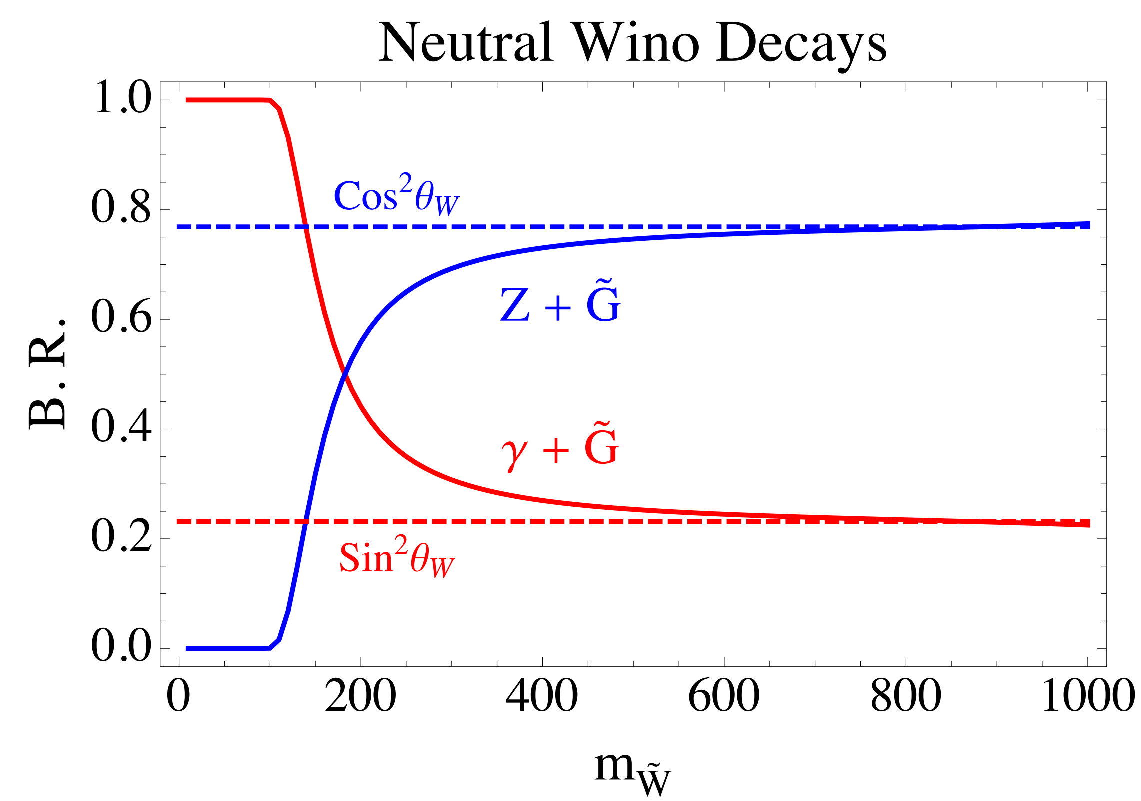
  - Electroweak production in SPS8 points: lower overall scale.
- The goal is to remain as model-independent as possible.

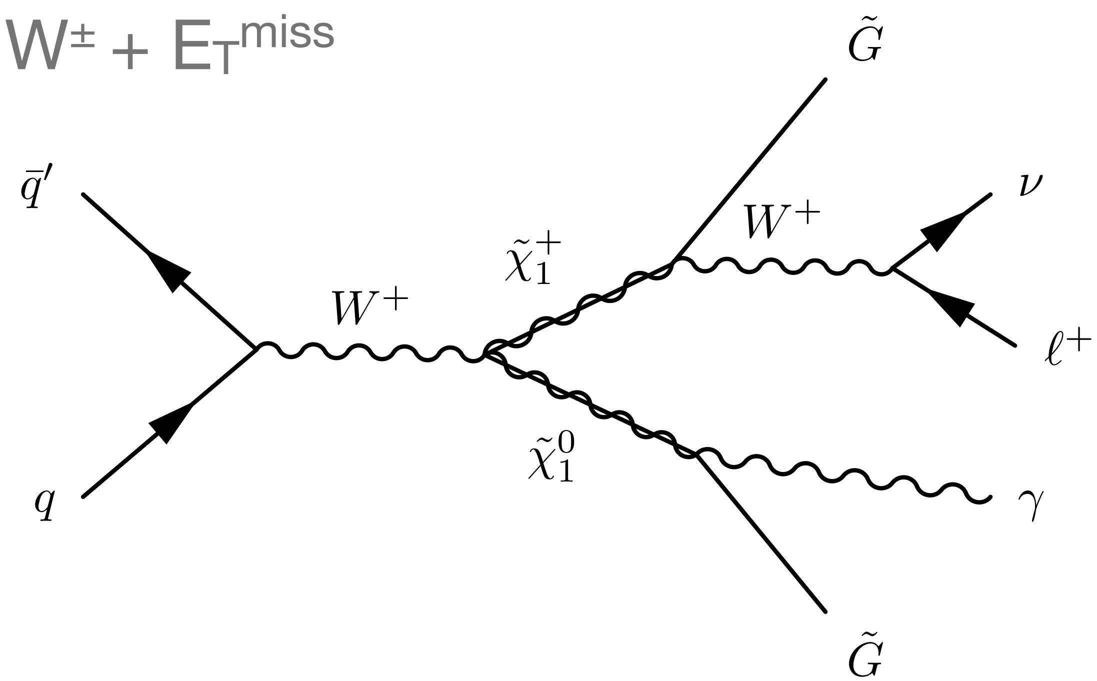
Other Potential Analyses

- Wino NLSP: photon + lepton
- Bino/Higgsino NLSP: photon + b-jets
- Nonpointing photons (generally bino NLSP)
- Aside on non-photon GMSB searches

Wino NLSP

- If $|M_2| << \mu$ and $|M_2| < |M_1|$, the lightest neutralino is wino-like
- The mass differences between $\widetilde{W}^{\pm}$ and $\widetilde{W}^0$ is small: co-NLSP.
- Decays from each side of chain are:
  - $\gamma + E_T^{miss}$
  - $Z + E_T^{miss}$
  - $W^{\pm} + E_T^{miss}$



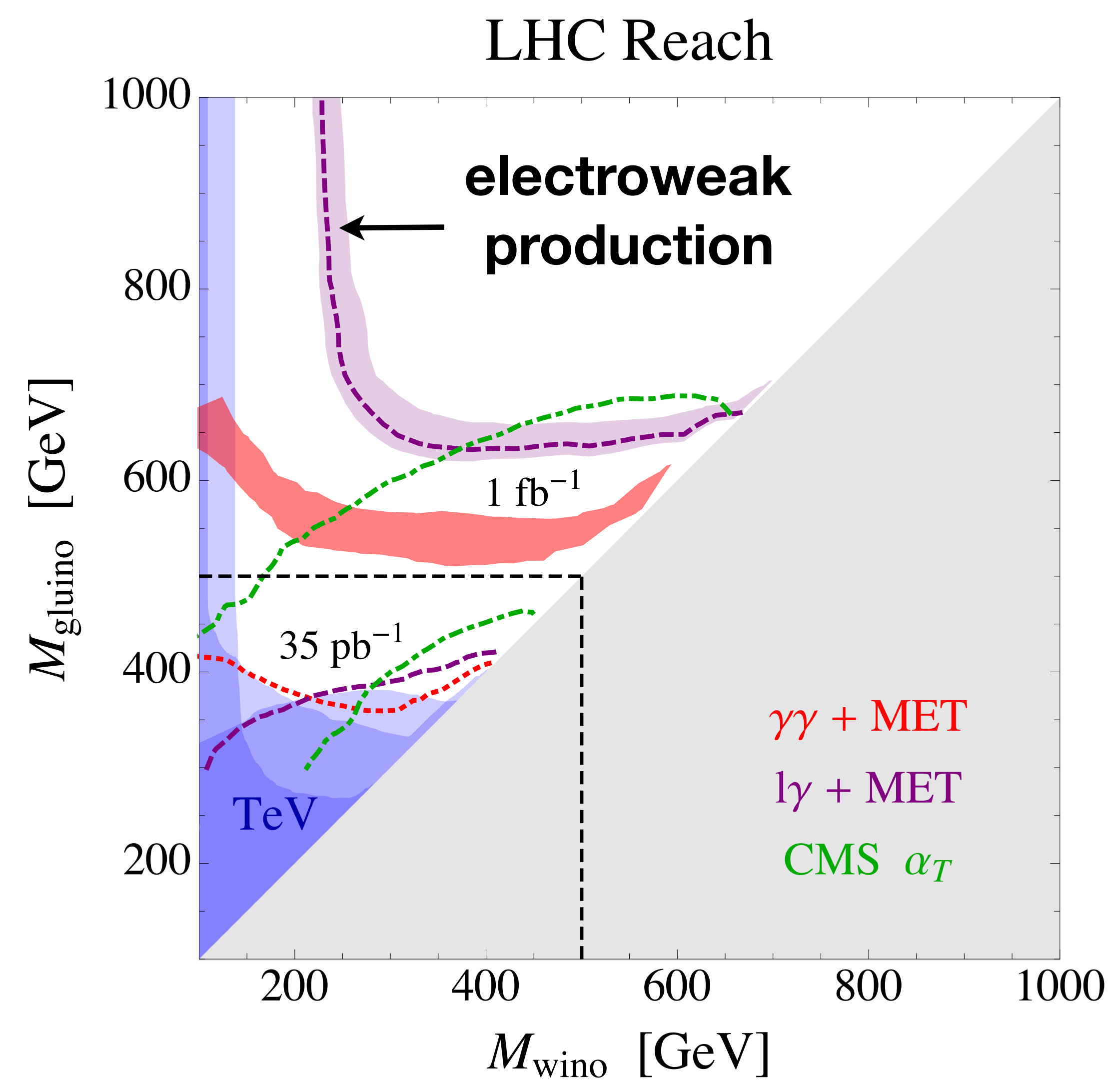


- Also an interesting channel for model-independent searches:

  e.g., technicolor signal: hep-ph/0702167v2

Wino NLSP: Potential Search Channel

- Standard jet+E_T^{miss} analyses can be re-interpreted to produce competitive limits for strong production
- A lepton + photon search can target weak production.
    - CMS has a result with 35 pb^{-1}.
- Main backgrounds:
    - SM Wγ
    - ttbar and ttbar+γ
    - W+jets, Z+γ, Z+jets



plot from arXiv:1103.6083v1 [hep-ph]
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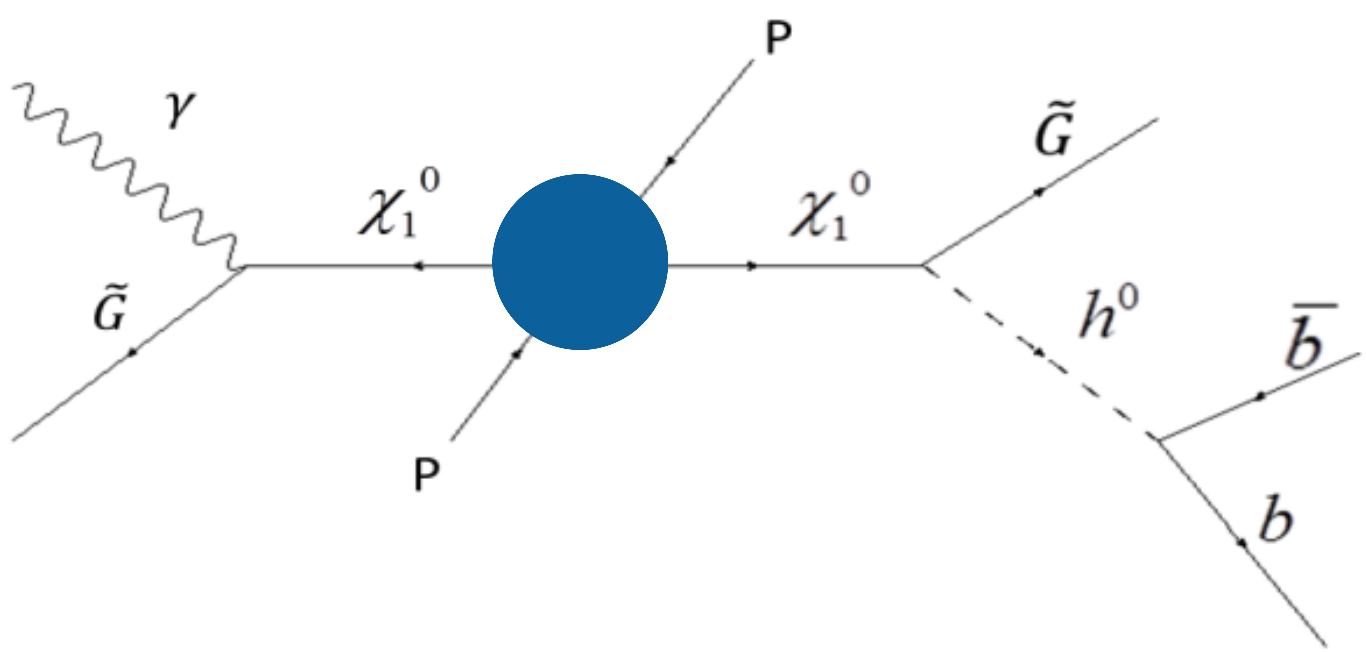
Bino / Higgsino NLSP

- It is possible for a neutralino to be a bino-higgsino admixture:
  - photons on one decay chain
  - *b*-jets on the other
- But also, γ + *b*-jet(s) is a particularly interesting channel: this is being pursued as a signature search.
- ttbar / ttbar + γ is the main background



Nonpointing Photons

- The decay of the NLSP to the gravitino is not prompt for a certain range of parameters:

$$\Gamma(\widetilde{X} \to X\widetilde{G}) = \frac{m_{\widetilde{X}}^5}{48\pi M_{\mathrm{P}}^2 m_{3/2}^2} \left(1 - m_X^2/m_{\widetilde{X}}^2\right)^4$$

- Assuming a bino-like NLSP, if the decay length is long enough to be measurable but not that long that the bino exits the inner detector, one can have a signal of **nonpointing** photons.
- Have a few handles:
  - LAr calorimeter timing
  - Calorimeter pointing
  - Calorimeter-tracker pointing for conversions

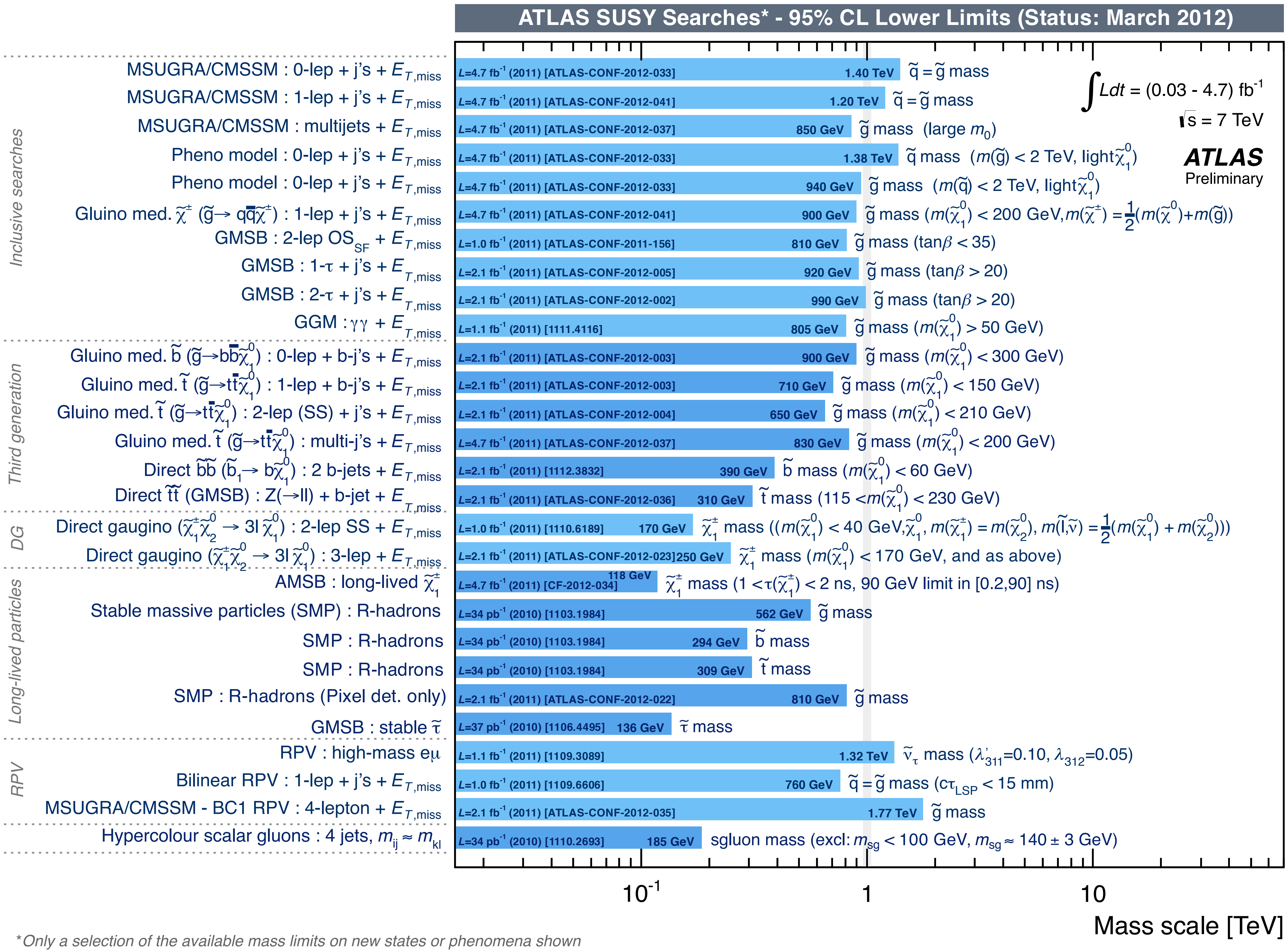
Aside: GMSB searches without photons

- GMSB does not require there to be photons in the final state.
- stau NLSP decaying to taus:
  - ≥ 2 taus: arXiv:1203.6580v1 [hep-ex]
  - ≥ 1 tau: ATLAS-CONF-2012-005
- stable stau NLSP: PLB 703 (2011) 428
- dilepton search: ATLAS-CONF-2011-156
- higgsino-like neutralino NLSP decaying to *Z*
  - ATLAS-CONF-2012-047
  - (and stop decaying to neutralino + *b*): ATLAS-CONF-2012-036

Conclusion

- ATLAS is searching for new physics in photons + E_T^{miss} channels.
- The primary, though not exclusive, theoretical framework is GGM
  - Nevertheless, we try to make the results as model-independent as we can.
  - We tend to use simplified models and only make selections on the primary features of the model.
- We are doing our part to push up the limits for strong production.
- We were also among the first ATLAS analyses looking for SUSY weak production.

Summary of ATLAS SUSY Searches



Backup

Mixing of States

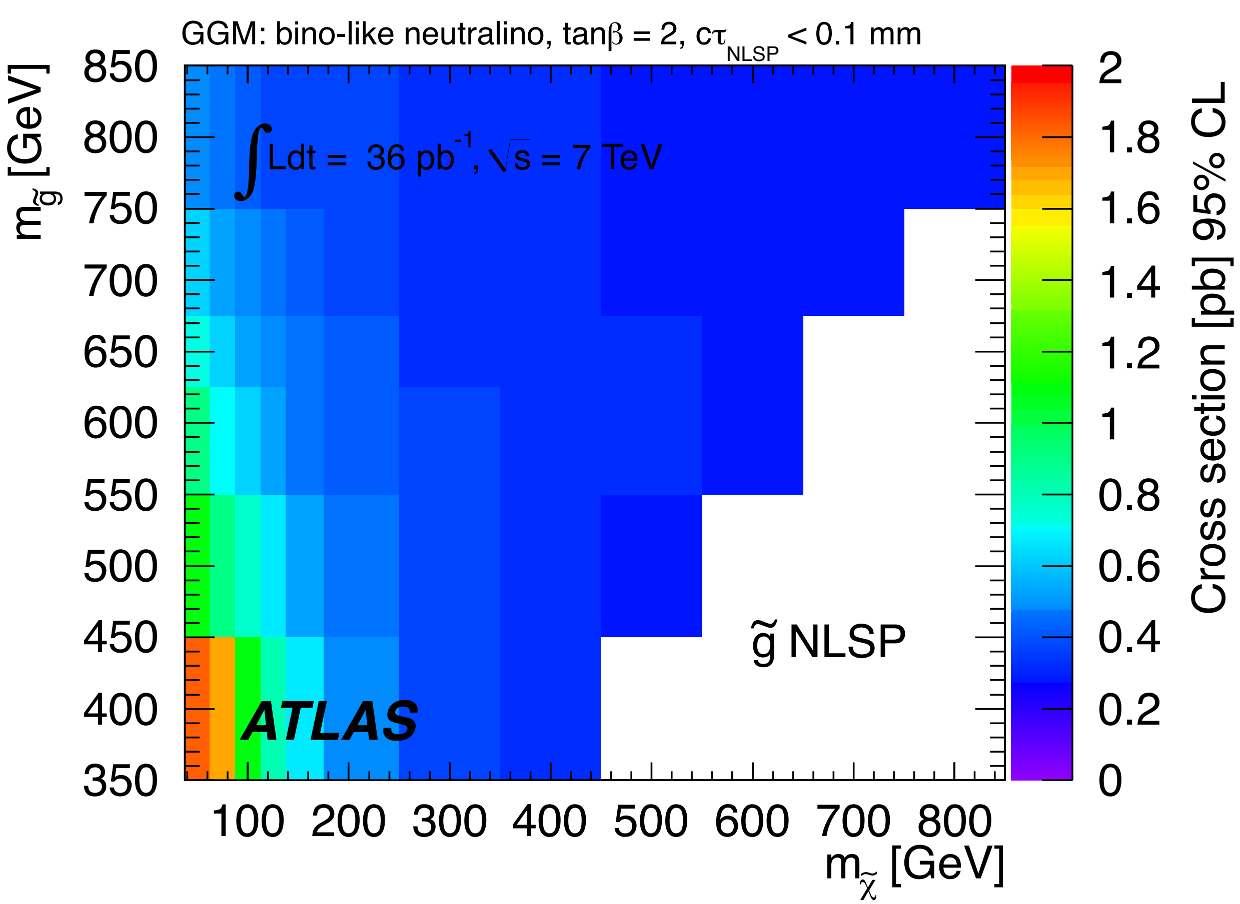
- The gauge eigenstates are not necessarily mass eigenstates.
- SUSY requires at least two Higgs doublets, so SUSY partners: $\tilde{H}_d^0, \tilde{H}_u^0, \tilde{H}_d^-, \tilde{H}_u^+$.
- The neutral gauginos and higgsinos $(\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$ mix to form the neutralinos $(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$ with the following mixing matrix:

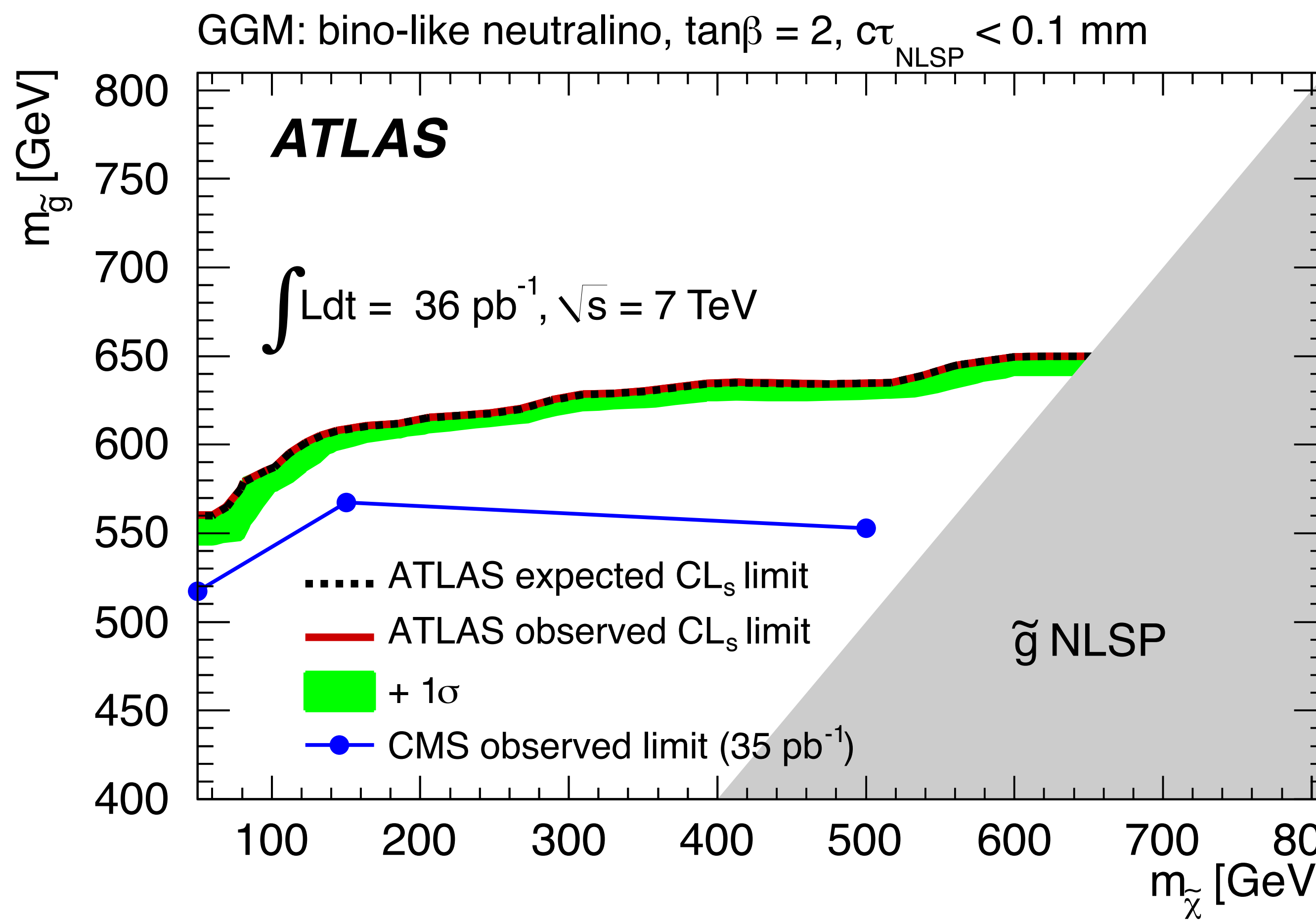
$$M = \begin{pmatrix} M_1 & 0 & -g'v_d/\sqrt{2} & g'v_u/\sqrt{2} \\ 0 & M_2 & gv_d/\sqrt{2} & -gv_u/\sqrt{2} \\ -g'v_d/\sqrt{2} & gv_d/\sqrt{2} & 0 & -\mu \\ g'v_u/\sqrt{2} & -gv_u/\sqrt{2} & -\mu & 0 \end{pmatrix}$$

- There is a similar mixing for the charged gauginos and higgsinos
- When I talk about a bino or wino NLSP, it is really saying that $\tilde{\chi}_1^0$ is made up mostly of $\tilde{B}$ or $\tilde{W}^0$ gauge eigenstates.

GGM Results with 2010 Data

- CL_s is used: model-independent 95% CL upper limit of 3.0 events
- CMS results from: https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS10002/table_mass_limits.txt



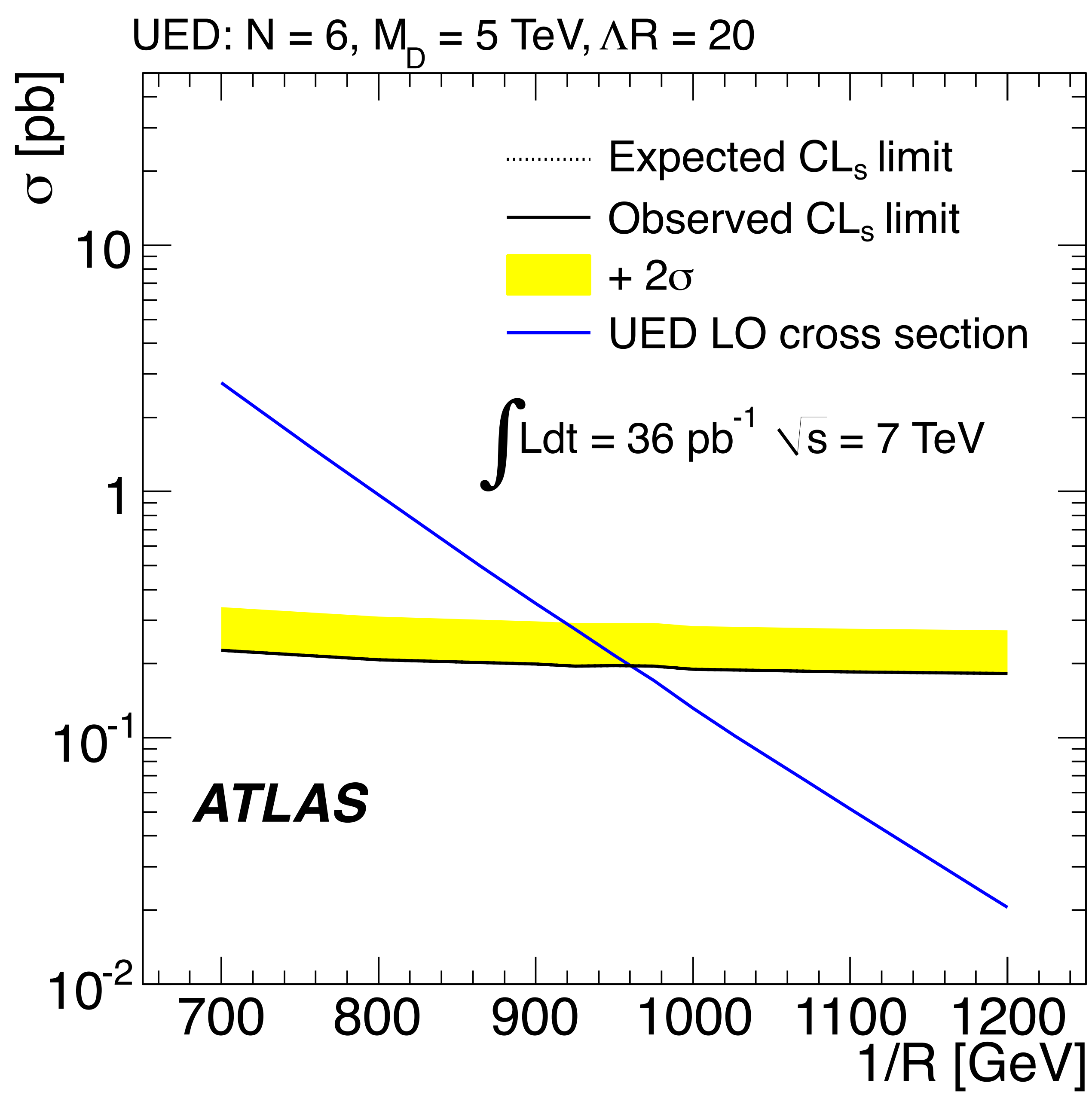


M_{gluino} > 560 GeV

for M_{bino} > 50 GeV

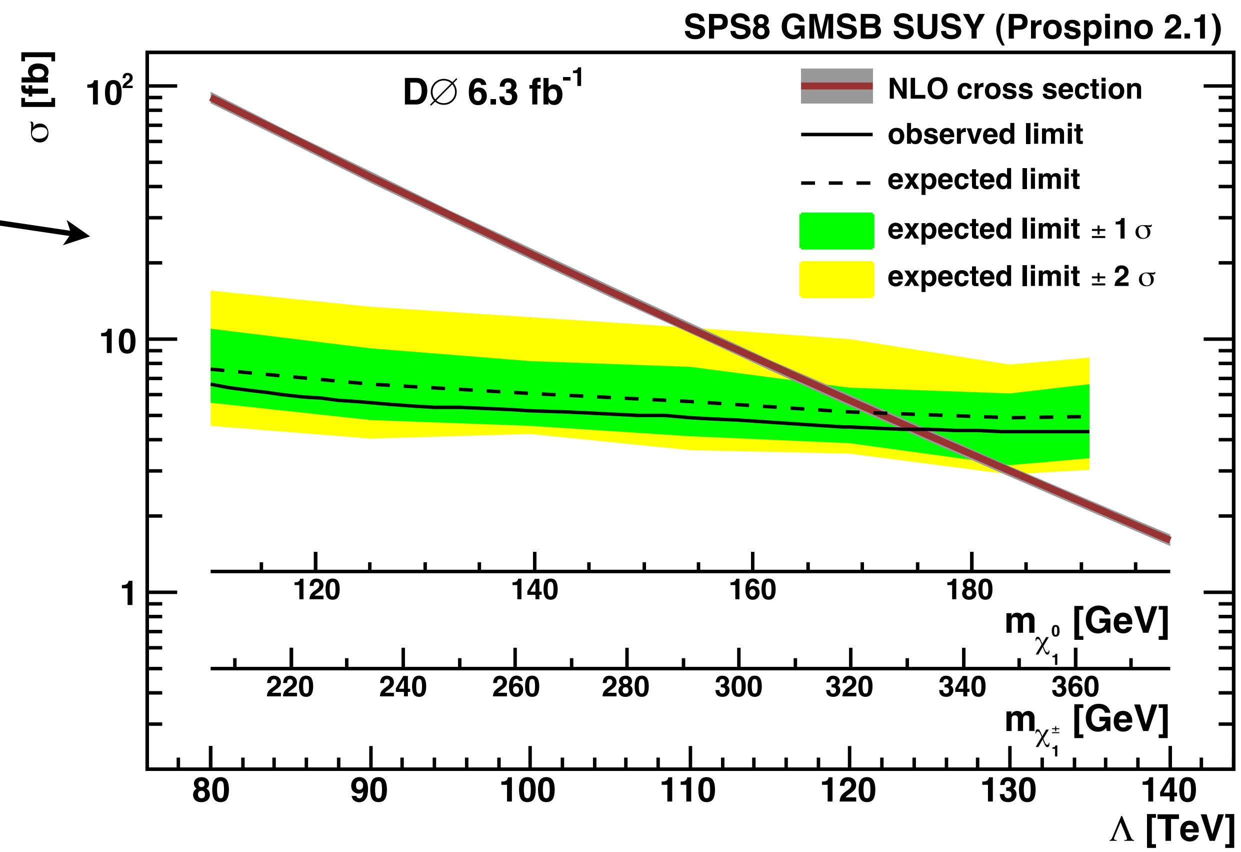
UED Result and Statistical Interpretation: 2010 Data

- CL_s is used: model-independent 95% CL upper limit of 3.0 events
- Model specific limit:
  1/R > 961 GeV
- Cross section limit:
  $\sigma < 0.18 - 0.23$ pb



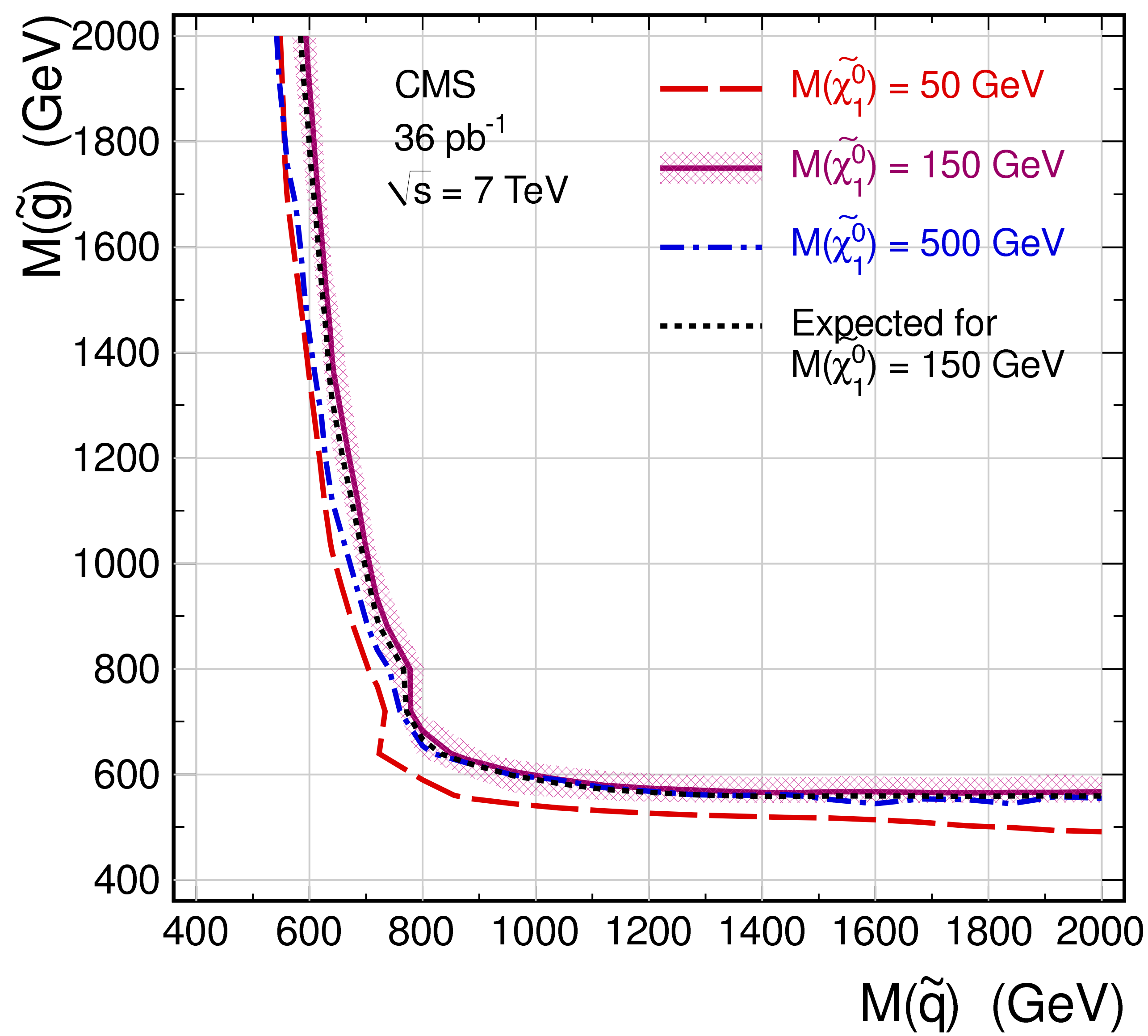
Latest D0 Result (arXiv:1008.2133v1)

- In MGM, D0 set a limit of $m_\chi > 175$ GeV in SPS8 framework.
- Current ATLAS analysis, if interpreted in the SPS8 trajectory, would produce a limit of $m_\chi > 124$ GeV
- 210 pb^{-1} would be needed to match the D0 sensitivity

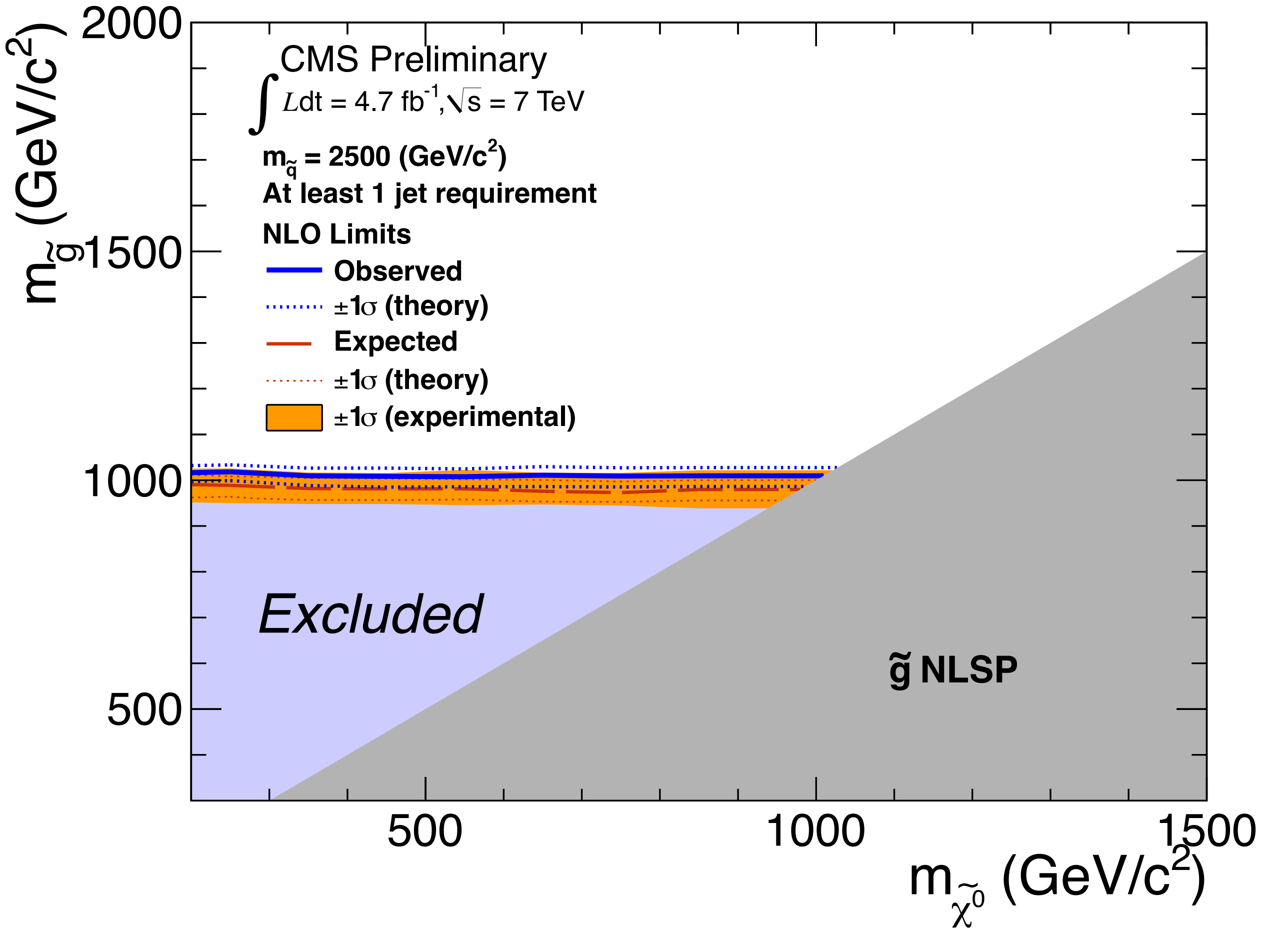


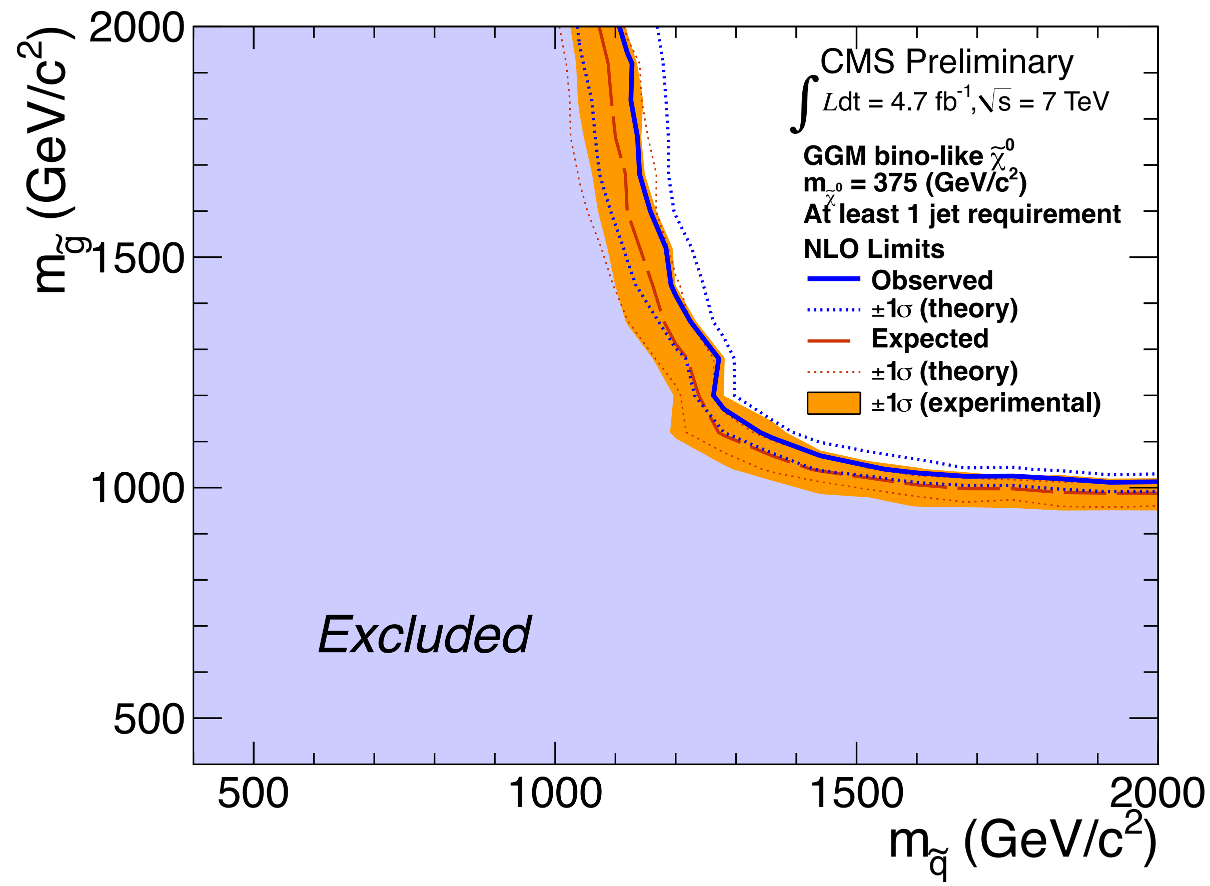
2010 CMS Result: arXiv:1103.0953v1 [hep-ex]

- No excess of events with E_T^{miss} > 50 GeV
- cross section limit between 0.3 and 1.1 pb at the 95% CL across.
- Extracted a contour while varying the gluino and squark masses

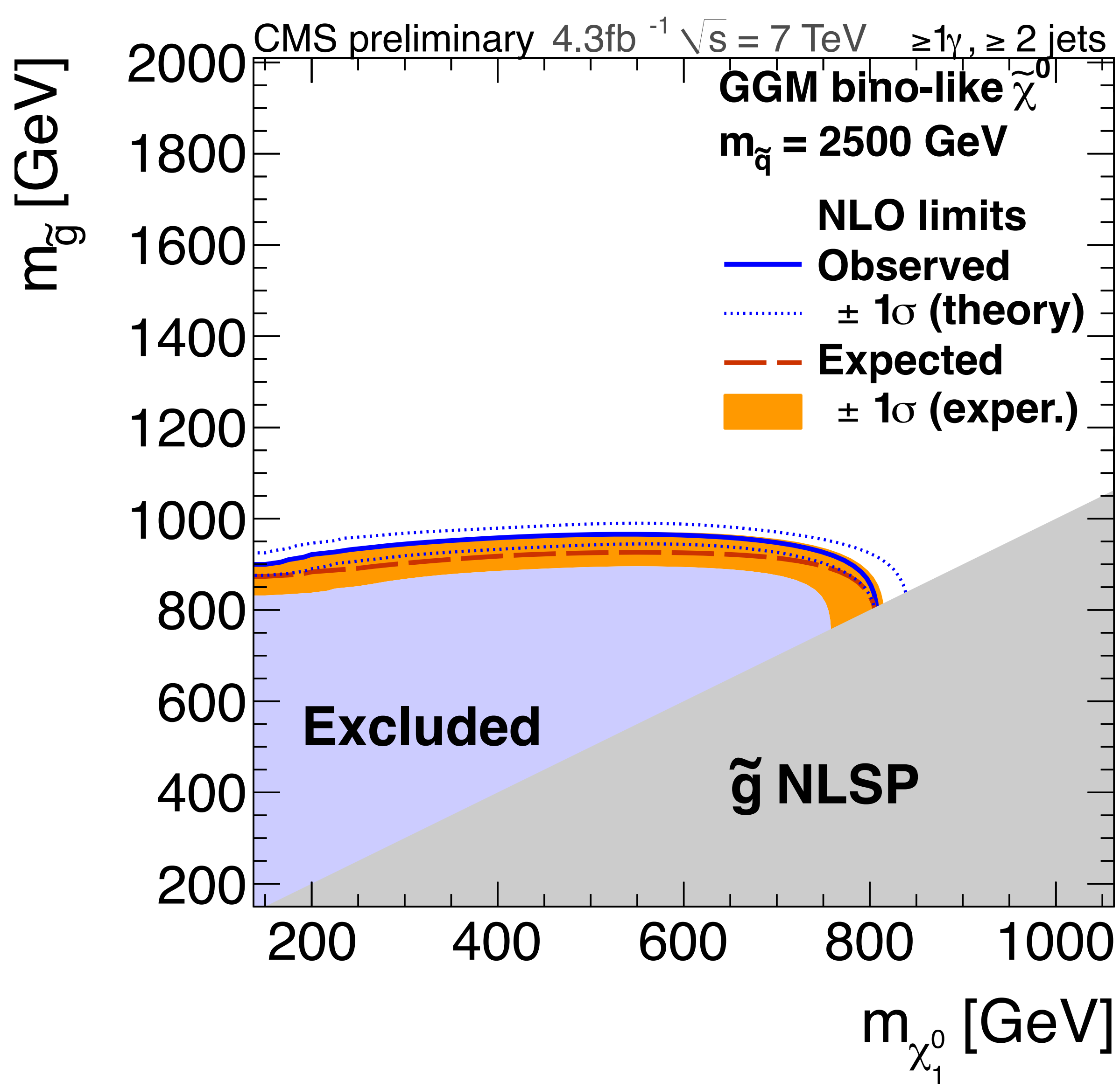


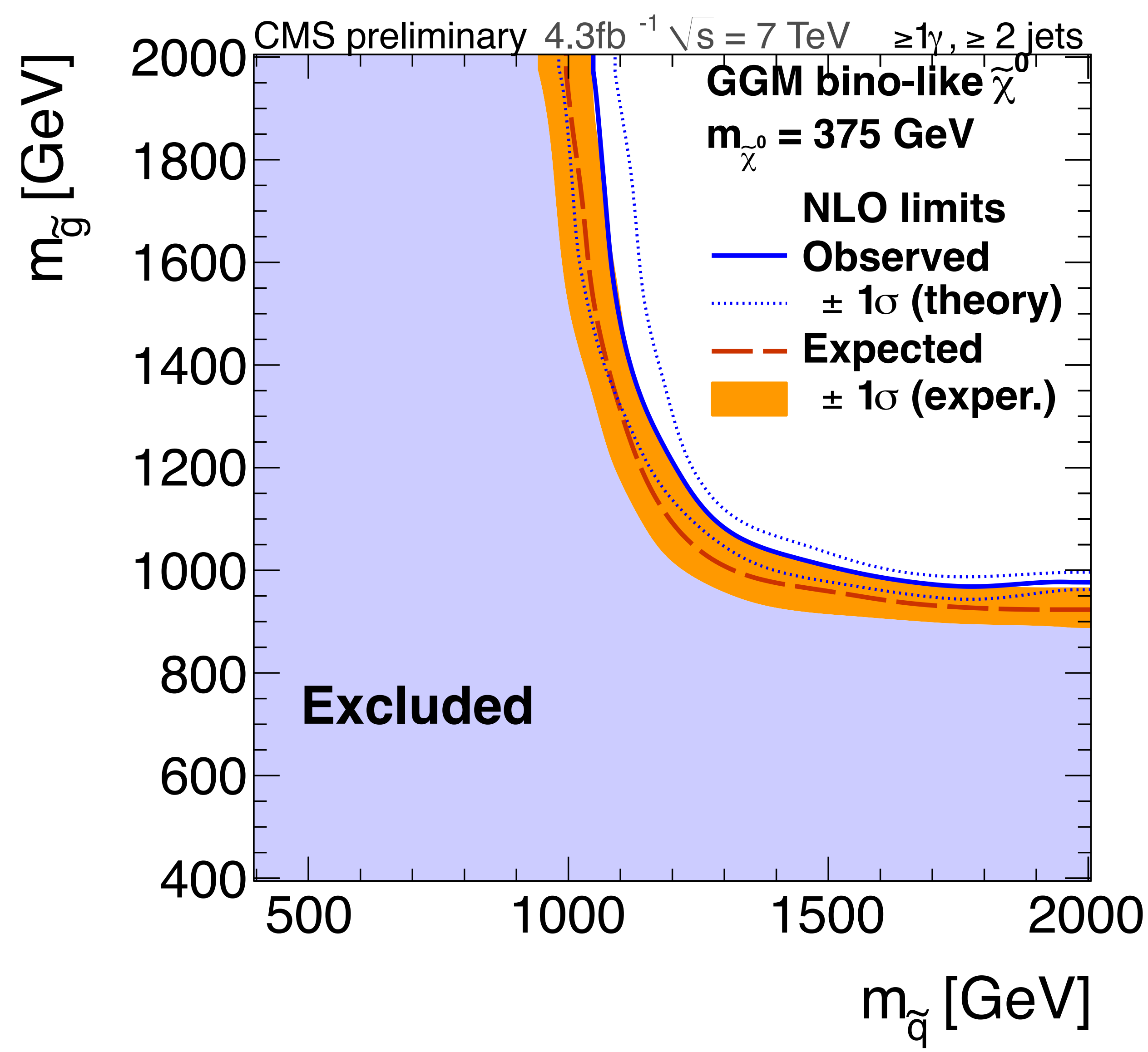
Latest CMS results: CMS PAS SUS-12-001
Diphoton analysis, bino-like NLSP



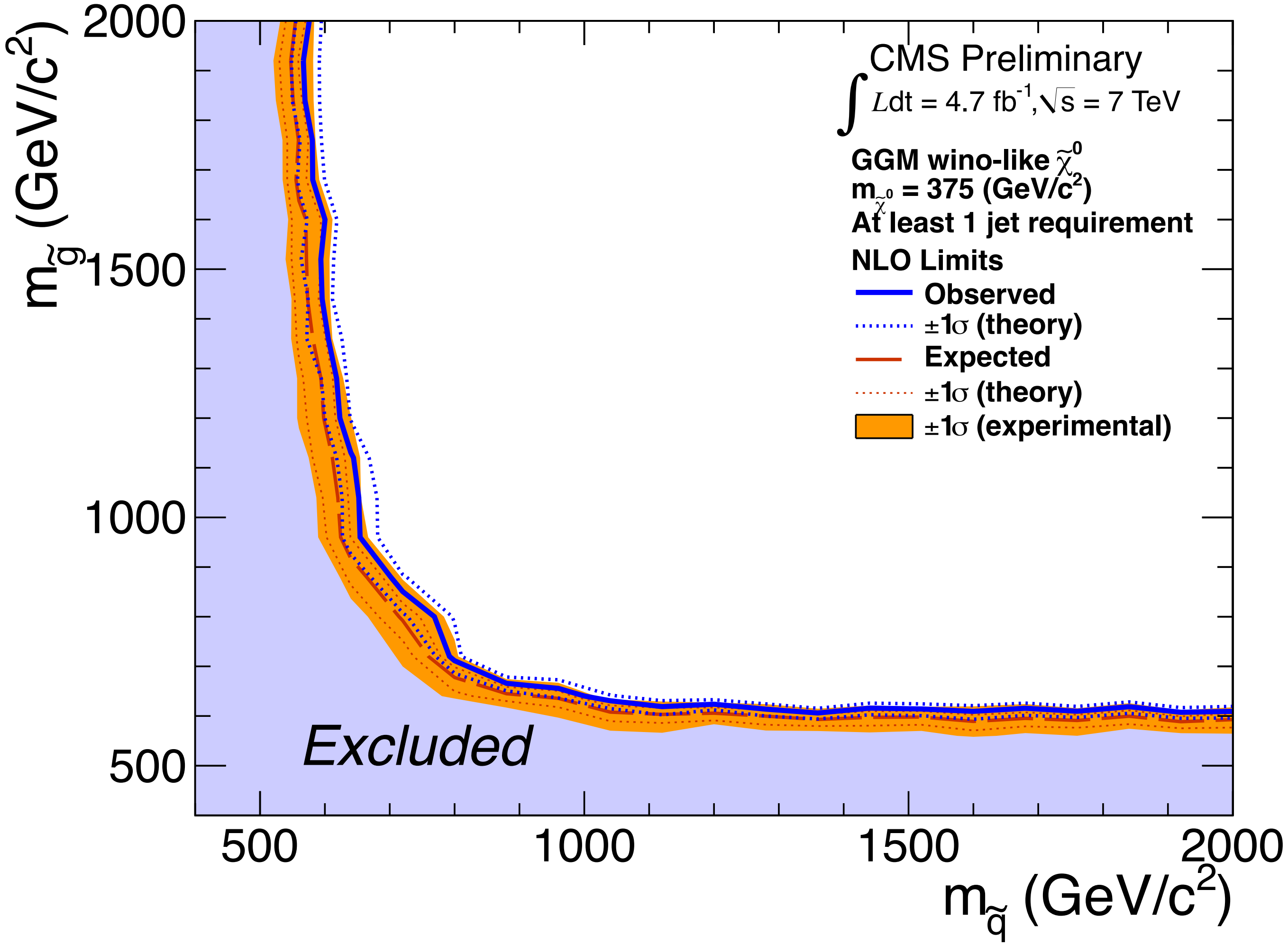


Latest CMS results: CMS PAS SUS-12-001 Single photon analysis, bino-like NLSP

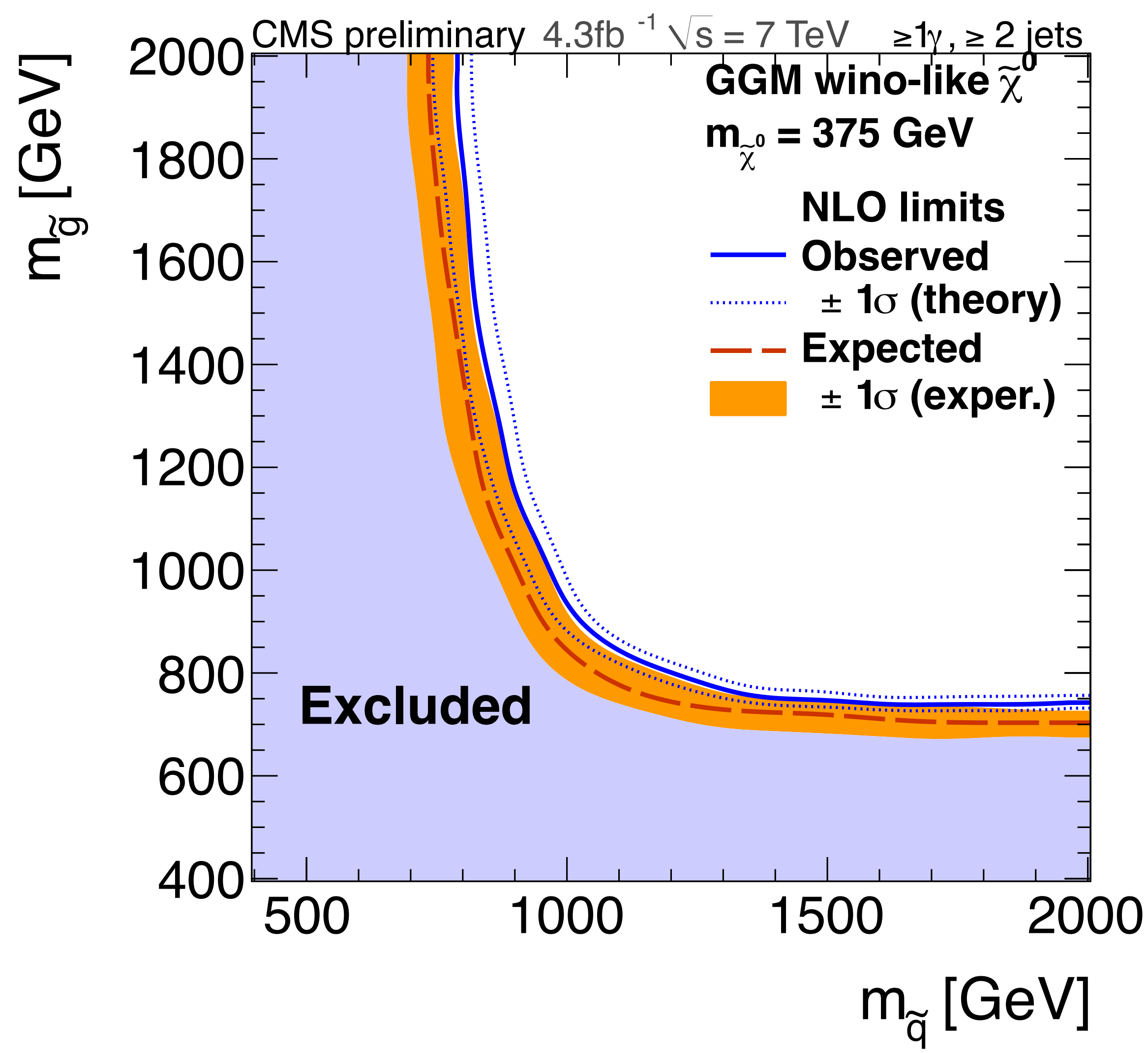




Latest CMS results: CMS PAS SUS-12-001 wino-like NLSP

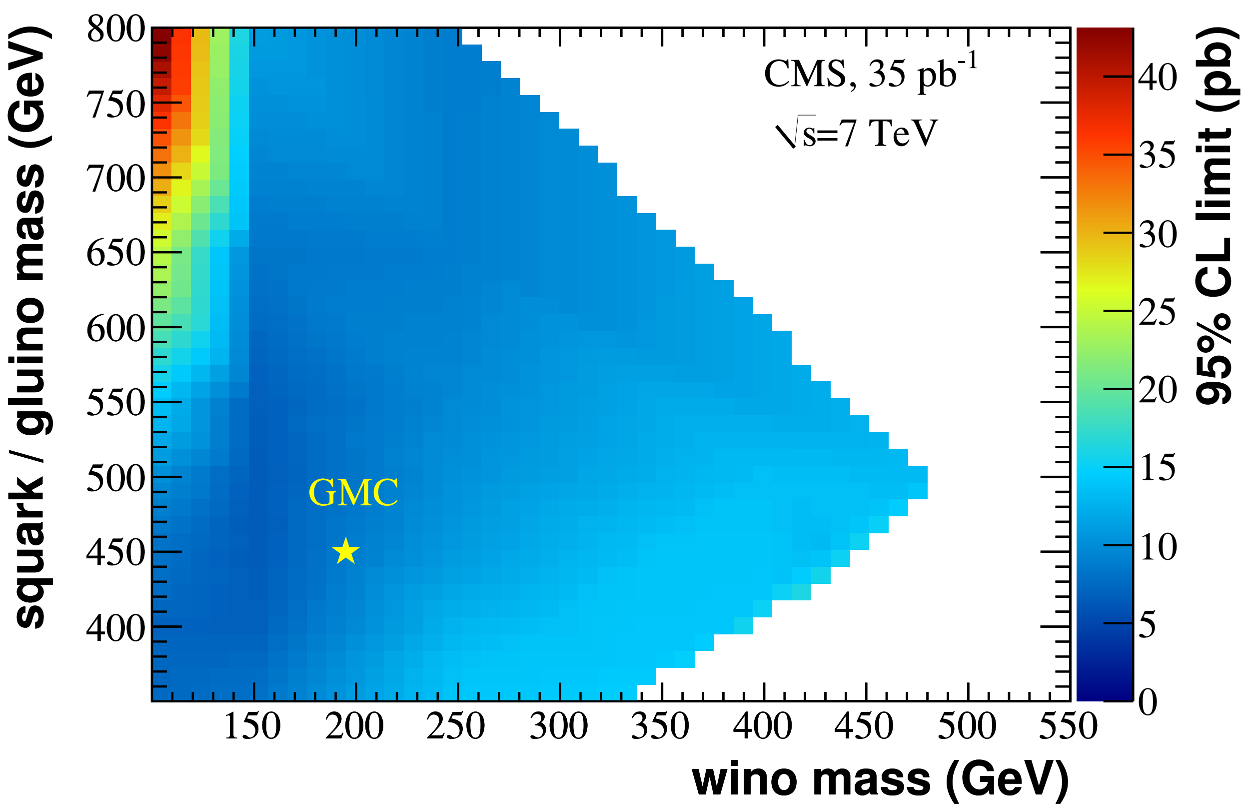


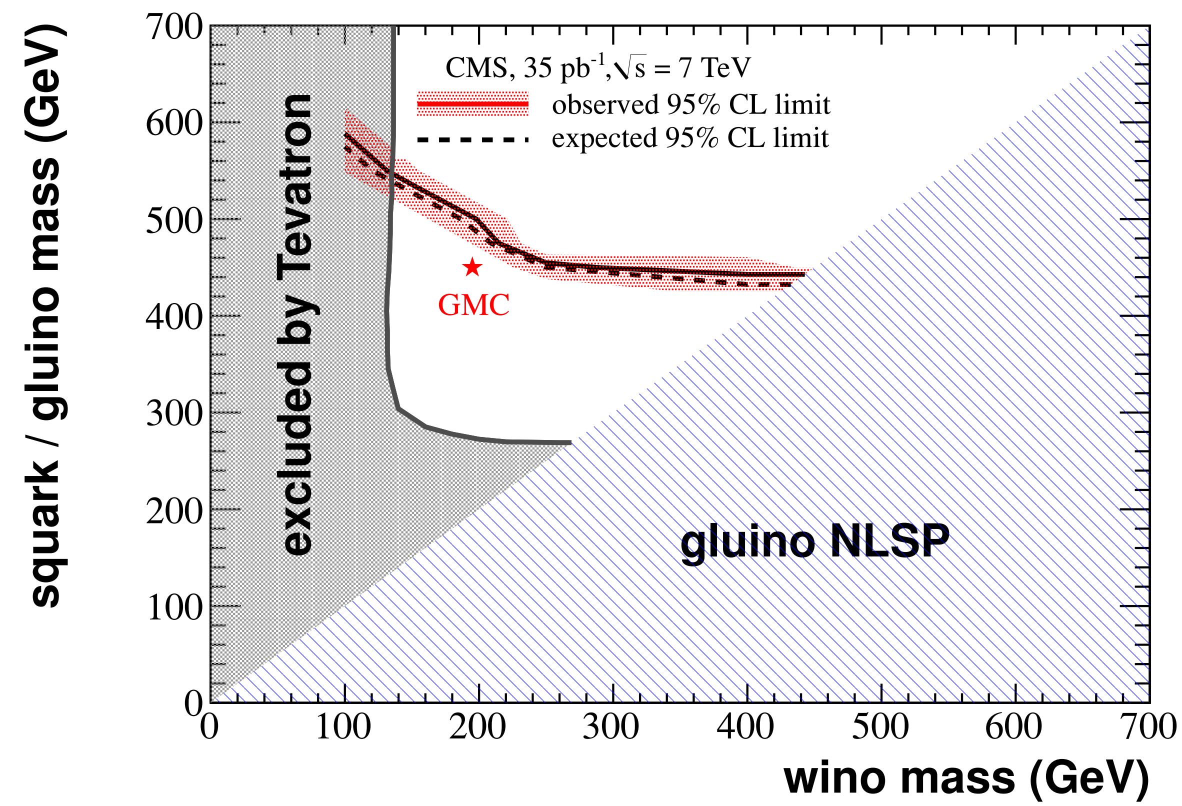
diphoton



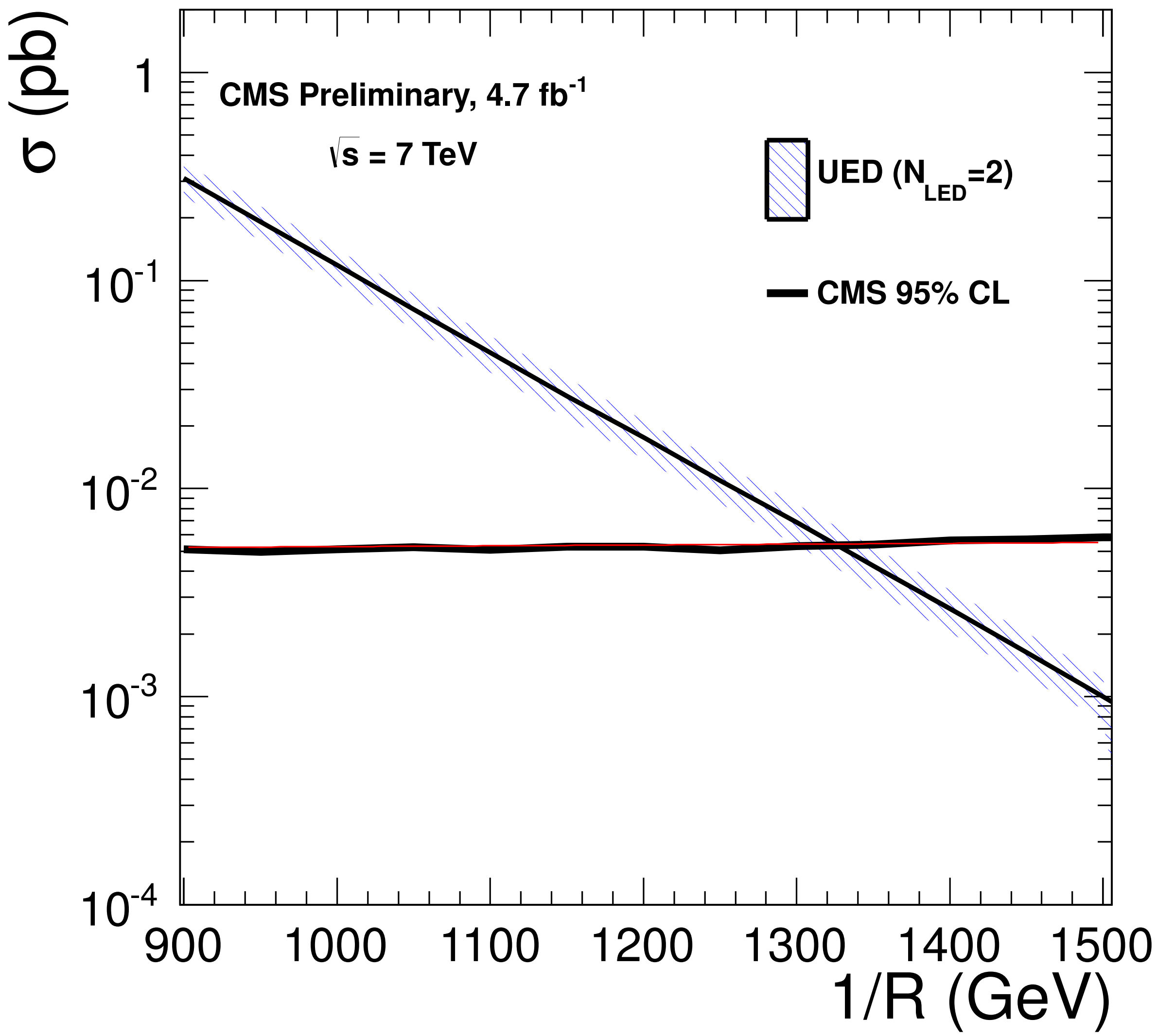
single photon

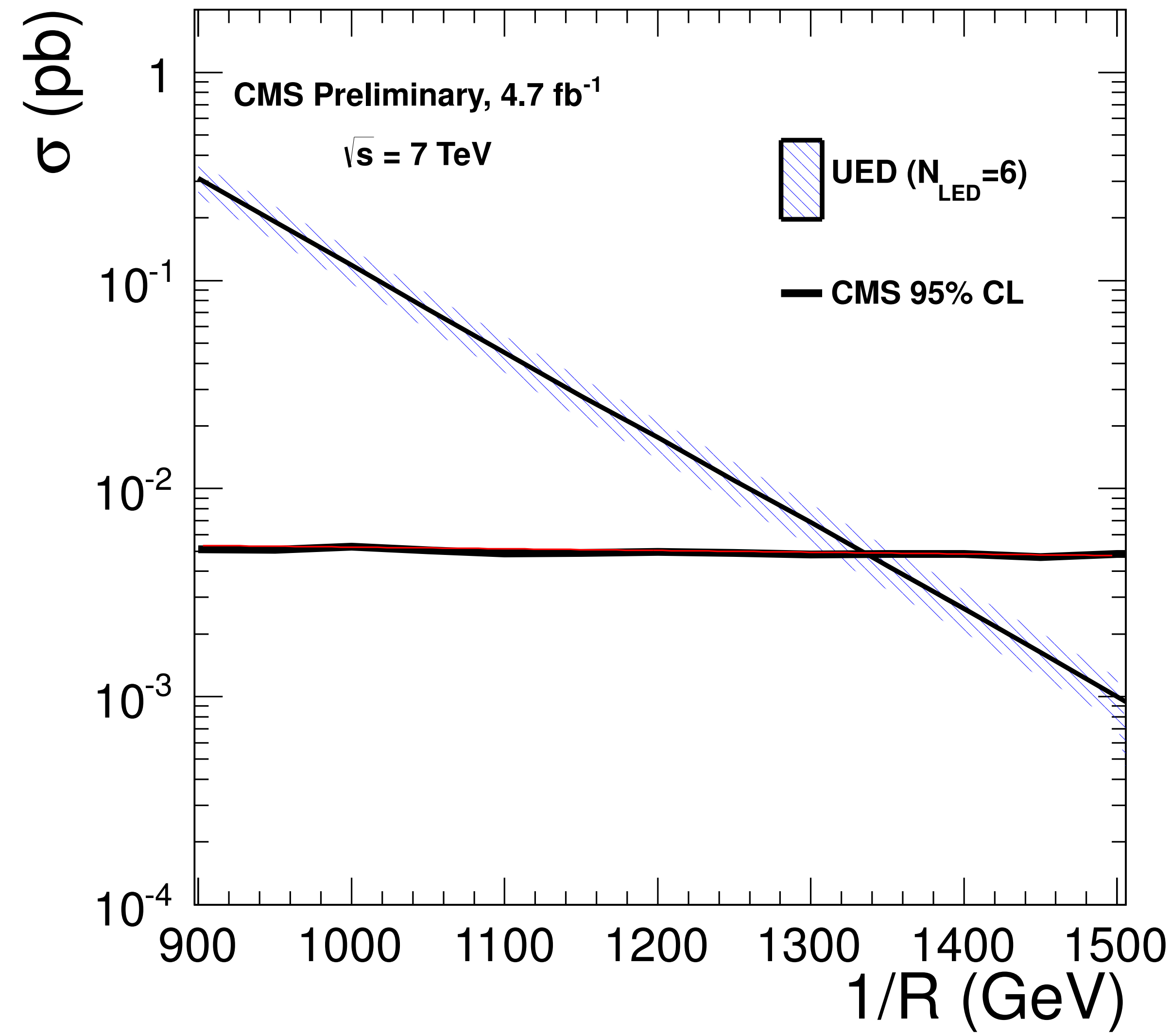
CMS 35 pb^{-1} lepton+photon results





Latest CMS results: CMS PAS SUS-12-001 UED



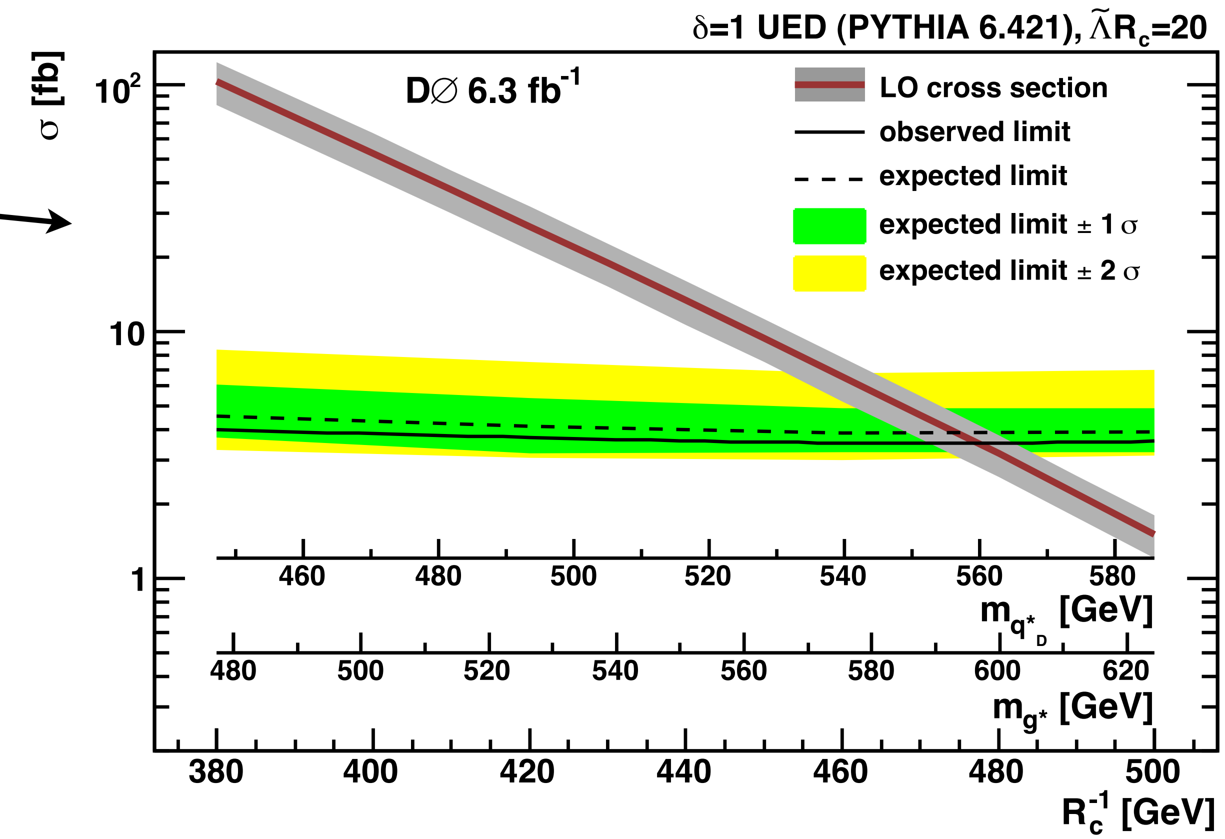


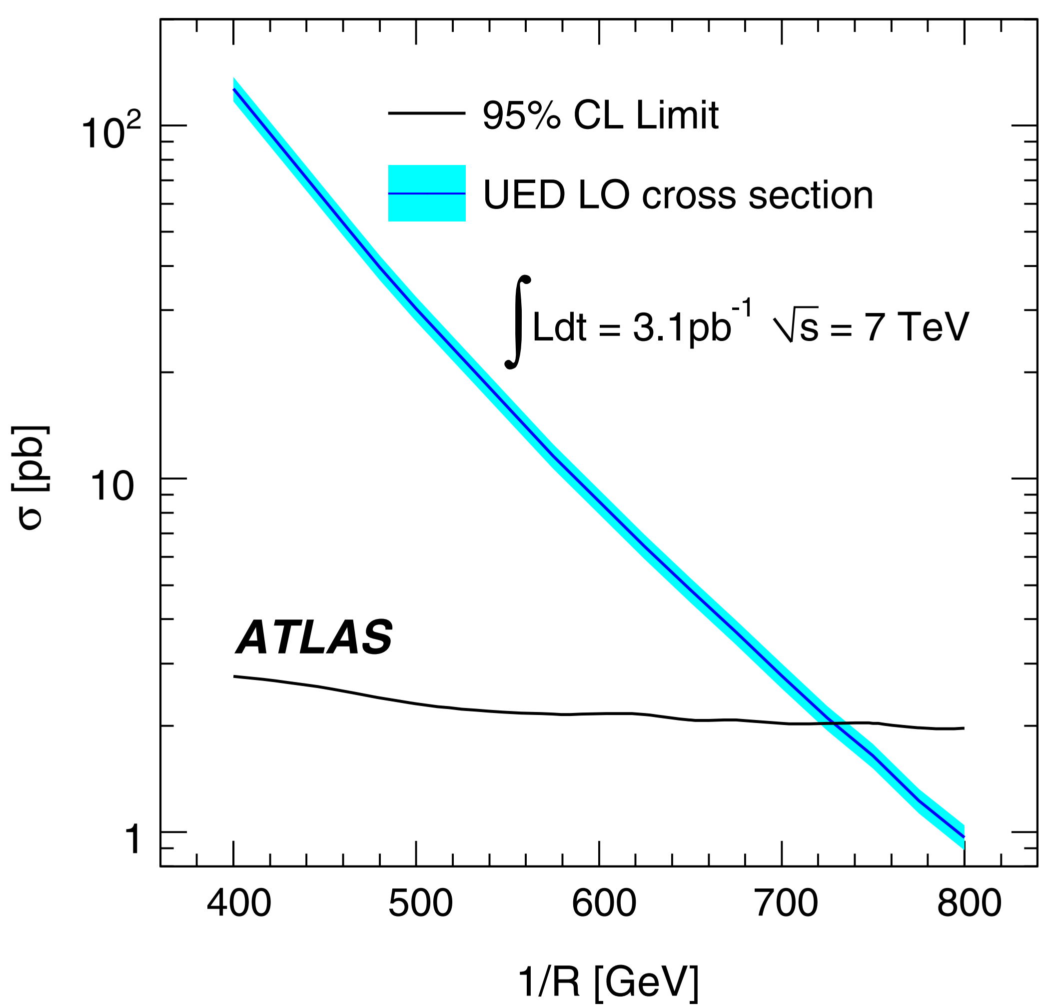
1/R > 1323 GeV

1/R > 1335 GeV

Older UED Results

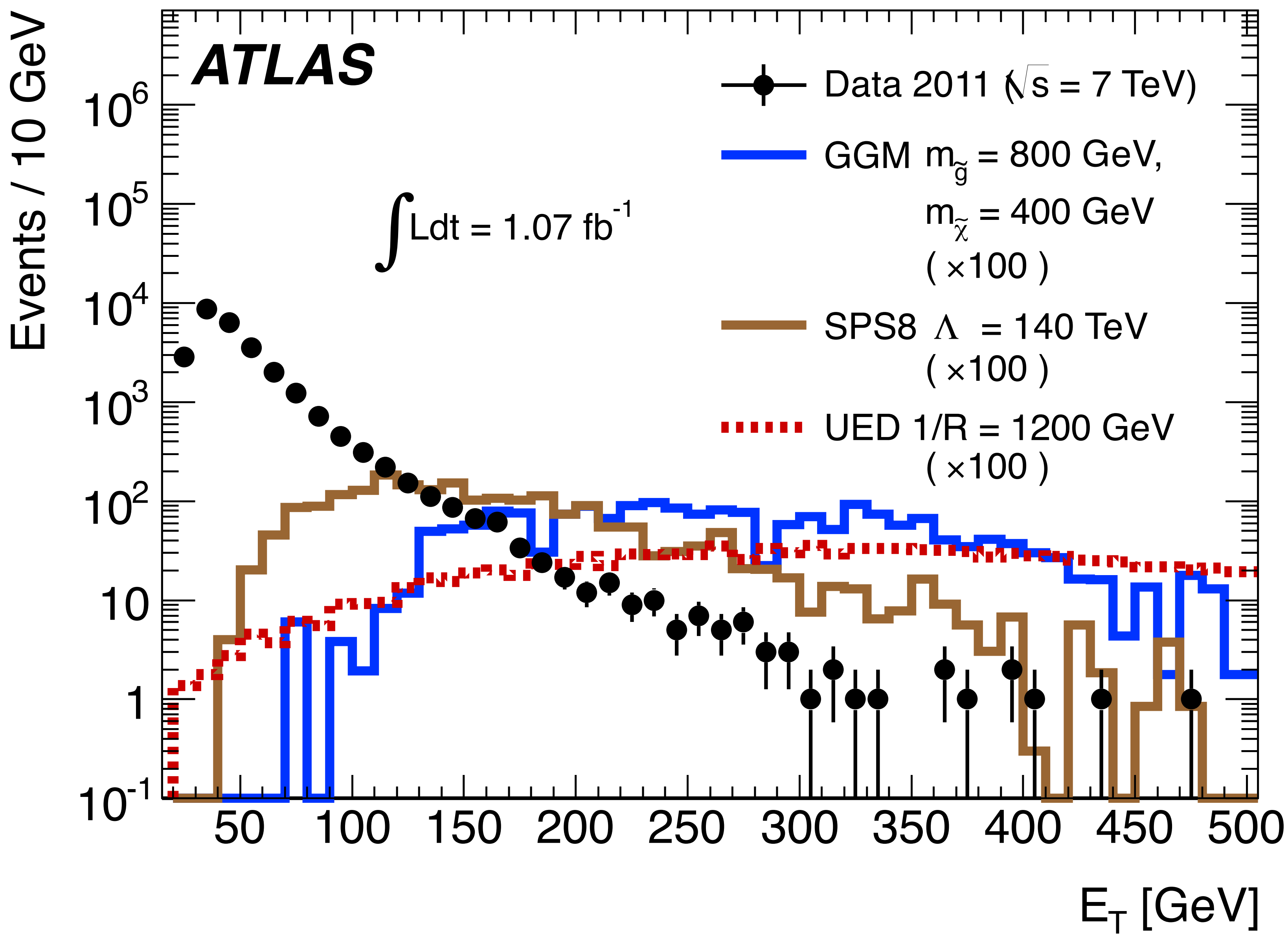
- For UED, D0 set a limit of $R^{-1} > 477$ GeV





- ATLAS set a limit of $R^{-1} > 729$ GeV

GSMB and UED Photon p_T distributions



isEM discriminating variables for photons

Category	Description	DV	Loose	Tight
Acceptance	$\|\eta\| < 2.37$, $1.37 < \|\eta\| < 1.52$ excluded	–		✓
Hadronic leakage	Ratio of E_T in the first sampling of the hadronic calorimeter to E_T of the EM cluster (used over the ranges $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$)	R_{had_1}	✓	✓
	Ratio of E_T in all the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \|\eta\| < 1.37$)	R_{had}	✓	✓
EM Middle layer	Ratio between the sum $E^{S2}_{3\times7}$ of the energies of the cells contained in a 3×7 $\eta \times \phi$ rectangle (measured in cell units), and the sum $E^{S2}_{7\times7}$ of the cell energies in a 7×7 rectangle, both centered around the cluster seed	R_η	✓	✓
	Lateral width of the shower in the η direction	w_{η_2}	✓	✓
	Ratio between the sum $E^{S2}_{3\times3}$ of the energies of the cells contained in a 3×3 $\eta \times \phi$ rectangle (measured in cell units), and the sum $E^{S2}_{3\times7}$ of the cell energies in a 3×7 rectangle, both centered around the cluster seed	R_ϕ		✓
EM Strip layer	Lateral shower width for three strips around maximum strip	$w_{s\,3}$		✓
	Total lateral shower width	$w_{s\,\mathrm{tot}}$		✓
	Fraction of energy outside core of three central strips but within seven strips	F_{side}		✓
	Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}		✓

Jet Cleaning

	Loose	Medium = Loose OR	***under discussion*** Tight = Medium OR
HEC spikes	HECf>0.5 && |HECQ|>0.5 or |neg. E|>60GeV	HECf>1-|HECQ|	
EM coherent noise	EMf>0.95 &&|LArQ|>0.8 && |eta|<2.8	EMf>0.9 && |LArQ|>0.8 && |eta|<2.8	|LArQ|>0.95 or EMf>0.98 && |LArQ|>0.05
Non-collision background & Cosmics	|t|>25ns or EMf<0.05 && Chf<0.05 && |eta|<2 or EMf<0.05 && |eta|>=2 or FMax>0.99 && |eta|<2	|t|>10ns or EMf<0.05 && Chf<0.1 && |eta|<2 or EMf>0.95 && Chf<0.05 && |eta|<2	EMf<0.1 && Chf<0.2 && |eta|<2 or EMf<0.1 && |eta|>=2 or EMf>0.9 && Chf<0.02 && |eta|<2

The e→γ Fake Rate

- Use tag and probe based on Z events:
  - tag: Medium electron, etcone20_corrected < 5 GeV, and fired g20_loose
  - probe: egamma object that has fired g20_loose
- Let e = efficiency for true electron to satisfy electron criteria
- Let f = efficiency for true electron to satisfy photon criteria
- The scale factor (s) that the eg sample needs to be scaled is then:

$$s = \frac{f}{e} = \frac{N_{\text{pass photon}}/N_{\text{probe}}}{N_{\text{pass electron}}/N_{\text{probe}}} = \frac{N_{\text{pass photon}}}{N_{\text{pass electron}}}$$

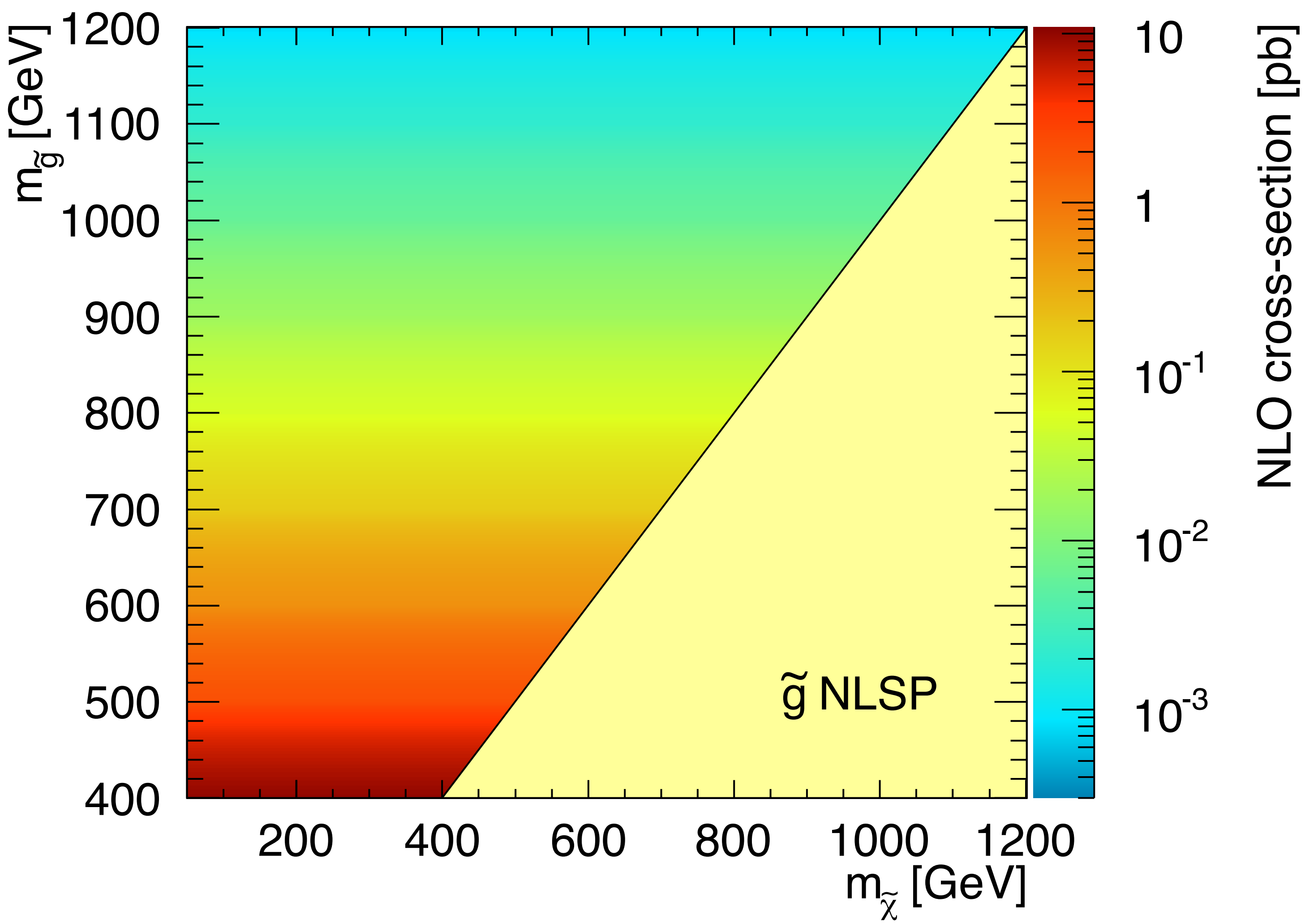
- Background subtraction can be done on the numerator and denominator. Use a Voigt function + exponential.

GMSB Cross Sections

SPS8

Λ[TeV	σ(LO)[pb]	σ(NLO)[pb]	K factor
50	12.2	18.0	1.482
60	4.38	6.49	1.482
70	1.83	2.69	1.468
80	0.855	1.24	1.446
90	0.436	0.617	1.415
100	0.240	0.331	1.379
110	0.141	0.189	1.341
120	0.0867	0.113	1.302
130	0.0557	0.0707	1.271
140	0.0370	0.0459	1.241
150	0.0252	0.0306	1.215
160	0.0176	0.0210	1.190
170	0.0125	0.0146	1.172
180	8.99×10^{-3}	0.0104	1.158
190	6.57×10^{-3}	7.49×10^{-3}	1.141
200	4.83×10^{-3}	5.47×10^{-3}	1.131
210	3.58×10^{-3}	4.02×10^{-3}	1.123
220	2.68×10^{-3}	2.99×10^{-3}	1.114
230	2.02×10^{-3}	2.23×10^{-3}	1.107
240	1.53×10^{-3}	1.68×10^{-3}	1.100
250	1.16×10^{-3}	1.27×10^{-3}	1.096

GGM



Irreducible Real E_T^{miss} background

- Z + γγ and W + γγ samples are modeled using Madgraph MC samples.
- K-factors were applied based on arXiv:1107.3149 [hep-ph] and Phys. Rev. **D83** (2011) 114035.
- 7.5% scale uncertainty assigned to Z (→νν)+ γγ.

Sample	K-factor	Yield (events)
Z (→νν)+ γγ	2.0 ± 0.3	0.23 ± 0.06
W (→ ℓ ν) + γγ	3 ± 3	< 0.06

Cosmic Background Estimate for 2010 analysis

- Estimated using real cosmic events triggered in empty bunches.
- Look for photons passing same p_T and η cuts, but no vertex or jet cleaning requirements
  - 7395 events with one loose photon, 63 with one tight
  - 2 events with two loose photons, 0 with two tight
    - Both two-loose photon events mass $E_T^{miss} > 125$ GeV
    - Estimate 0.017 ± 0.012 (statistical errors only) for two tight
- Scaling the results to the number of colliding bunches in our sample, and assuming all of the cosmics events would pass the E_T^{miss} cut:
  - 0.079 ± 0.056 two-loose, 0.00068 ± 0.00049 two-tight events
  - Therefore apply tight timing to QCD sample; negligible for signal

Acceptance Systematics due to E_T^{miss}: 2010 analysis

- Reminder: we use a E_T^{miss} based on the topocluster energies, corrected for muon terms.
- Method to determine systematics inspired from W/Z cross section and previous UED analyses.
  - Topocluster Energy Scale: scale topocluster energy by uncertainty
  - Smear E^{miss}_x and E^{miss}_y for uncertainty due to resolution
  - Underlying event uncertainty within statistical error of MC sample
  - Muon term uncertainty found to be negligible.
- Total uncertainty: 10.9% to 0.8% (GGM) and 2.1% to 0.9% (UED)

Minimal Gauge Mediation (MGM)

following description by Steven P. Martin in arXiv:hep-ph/9709356v5

- Messengers couple to both:
  - the ultimate source of SUSY breaking
  - the MSSM via the standard gauge interactions
- In the simplest model ($N_{\text{mess}} = 1$), the messengers form chiral supermultiplets (ℓ and *q*) which couple to a chiral singlet (*S*)

$$W_{\text{mess}} = y_2 S \ell \bar{\ell} + y_3 S q \bar{q}$$

- *S* is assumed to acquire a vev, thus breaking the symmetry
- The gaugino masses (at the messenger scale) are given by:

$$M_a = \frac{\alpha_a}{4\pi} \Lambda$$

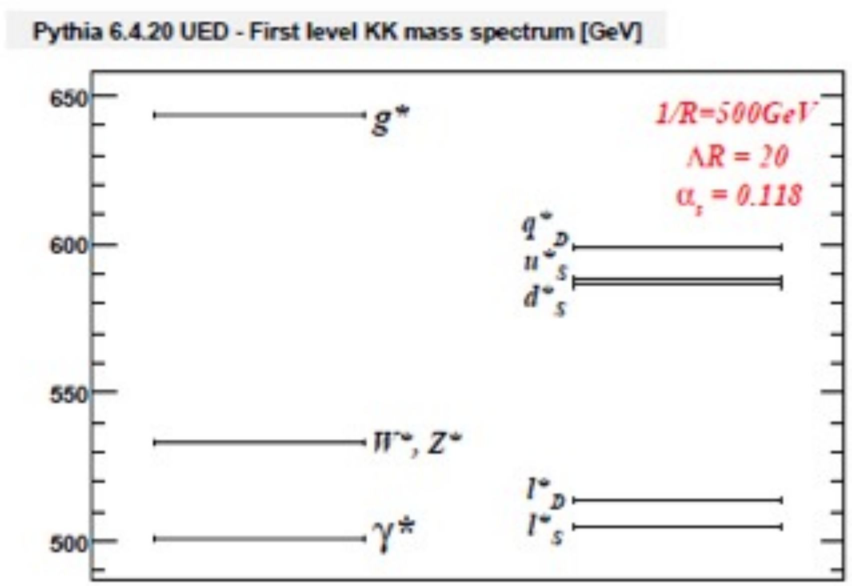
- where $\Lambda \equiv \langle F_S \rangle / \langle S \rangle$ and there is a suitable normalization for α_a.

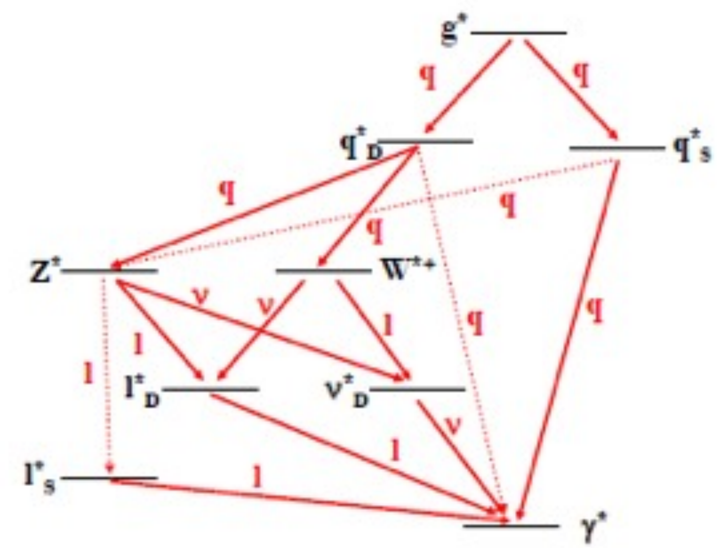
P. Meade, N. Seiberg, D. Shih
Prog.Theor.Phys.Suppl. 177 (2009) 143-158

Introduction to General Gauge Mediation

- Main principle: if the gauge coupling strength were to go to zero, then the SUSY breaking sector and the MSSM sector would decouple.
- This results in the following requirements:
  - Flavor universality among the sfermion masses
  - Certain sum rules are followed
  - Small A terms
  - Lightest supersymmetric particle (LSP): Gravitino
- The MGM mass hierarchy between the gauginos is not required.
- The NLSP flavor is much less restricted.

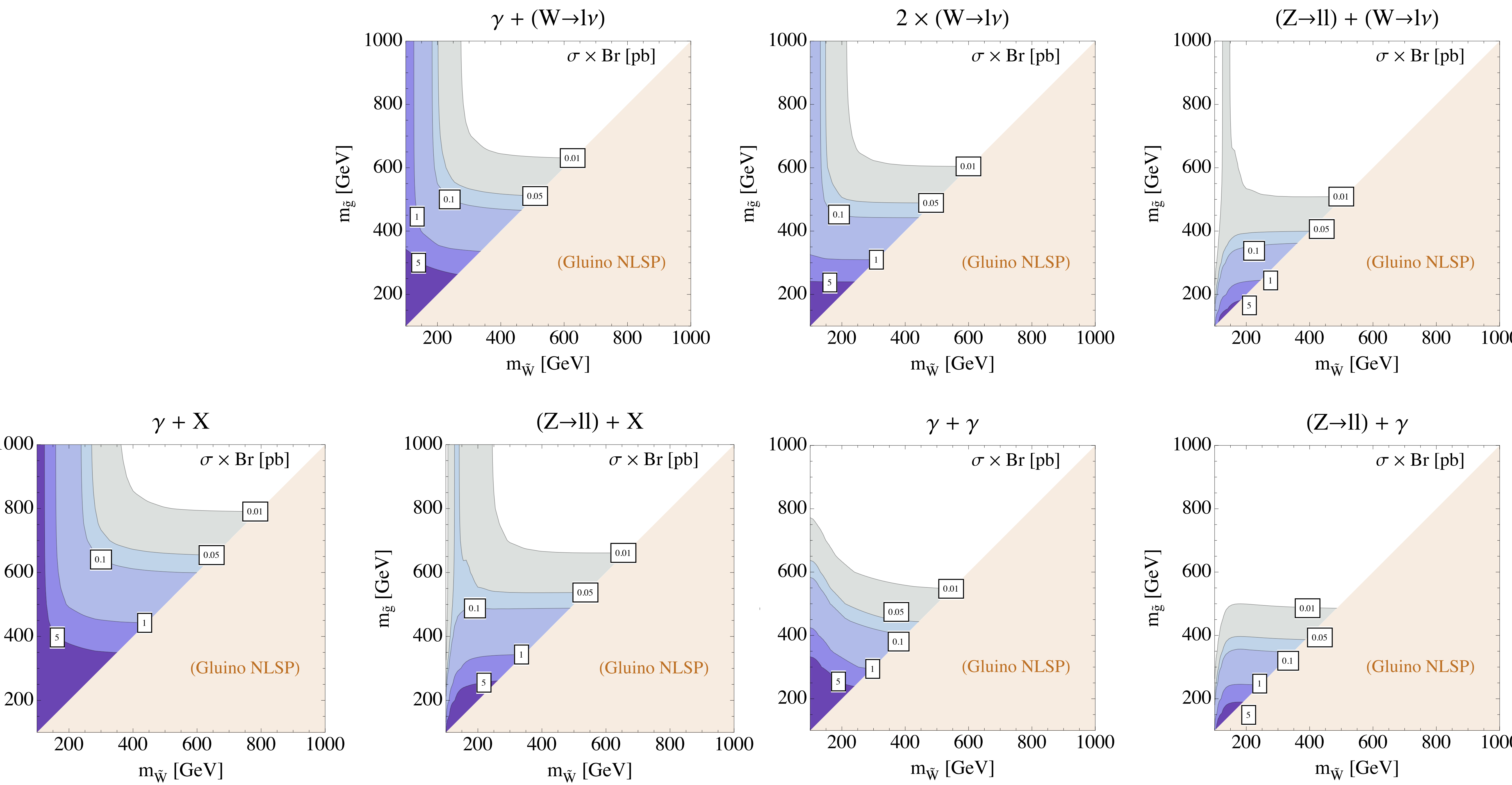
Introduction to Universal Extra Dimensions (UED)

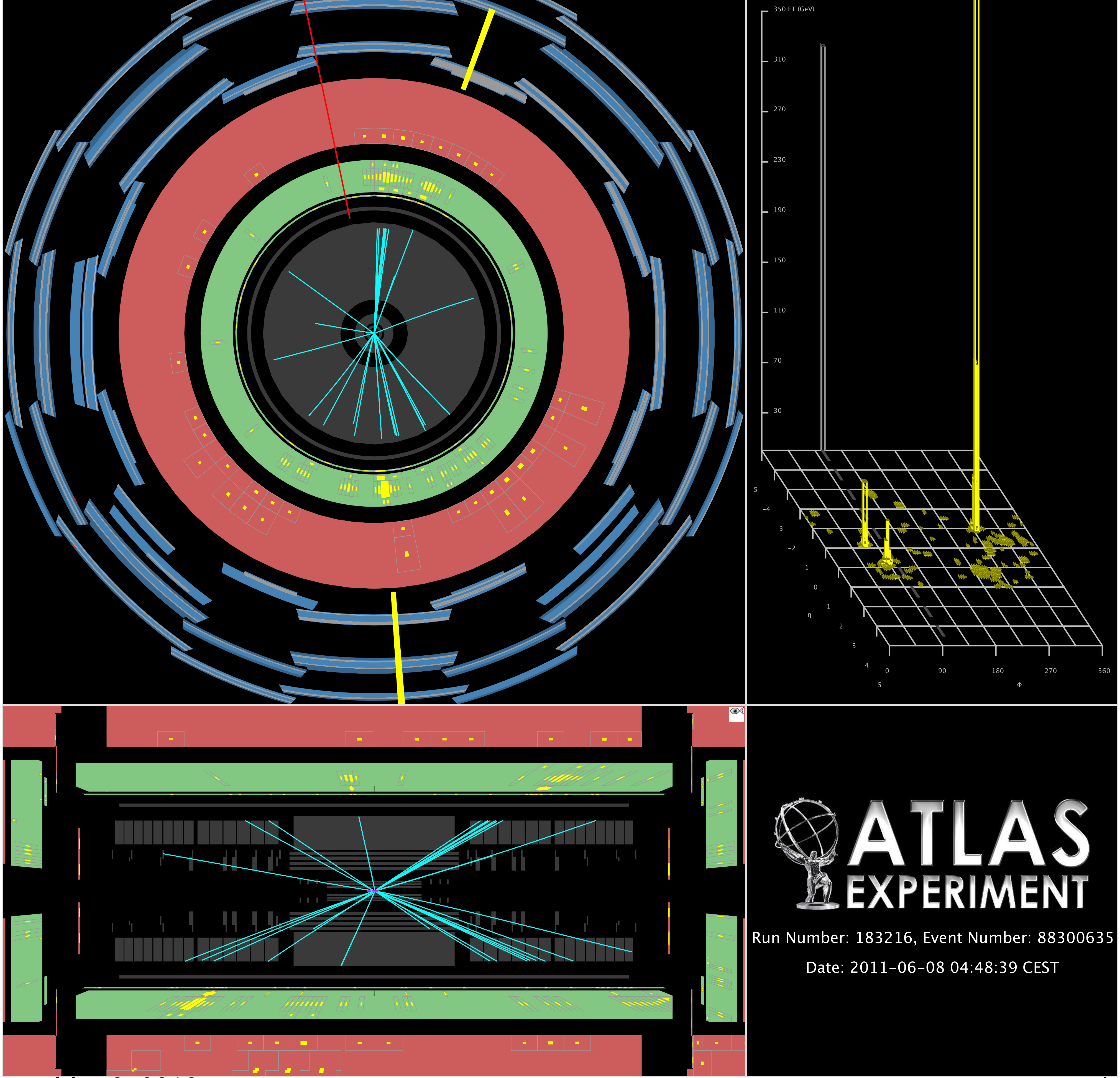




- **Universal**: ALL SM particles propagate into the extra dimensions (δ = 1; 1/R~1TeV)
- n=1,2,3,… Kaluza Klein (KK) excitations for each SM particle (n=0)
- R: compactification scale
- Mass degeneracy $m_n^2=n^2/R^2 + m_{SM}^2$ lifted by radiative corrections.
- quark and gluon KK excitations cascade decay down to Lightest KK Particle: γ*

Cross Sections for Wino Co-NLSP




350 ET (GeV)
310
270
230
190
150
110
70
30
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ
ATLAS
EXPERIMENT
Run Number: 183216, Event Number: 88300635
Date: 2011-06-08 04:48:39 CEST

Electron/Photon Ambiguity Resolution

- egamma cluster has matched trackParticle?
  - no: → Photon (Author 4)
  - yes: has matched conversion vertex?
    - no: is electron track bad (TRTSA, E/p > 10, or p_T < 2 GeV)?
      - yes: → Photon (alternate criteria)
      - no: → Electron
    - yes: is the electron track (one of) the tracks from the conversion vertex?
      - yes: Single or double-track conversion?
        - single: → Photon
        - double: Are there either 0 or 2 b-layer hits (vs 1)
          - yes: → Photon
          - no: → is electron track bad?
            - yes: → Photon (alternate criteria)
            - no: → Electron
    - no: is the electron track p_T > vector sum of conversion track p_Ts?
      - yes: → is electron track bad?
        - yes: → Photon (alternate criteria)
        - no: → Electron
      - no: → Photon

Glossing over dead b-layer modules

More on conversions (2008 JINST 3 S08003)

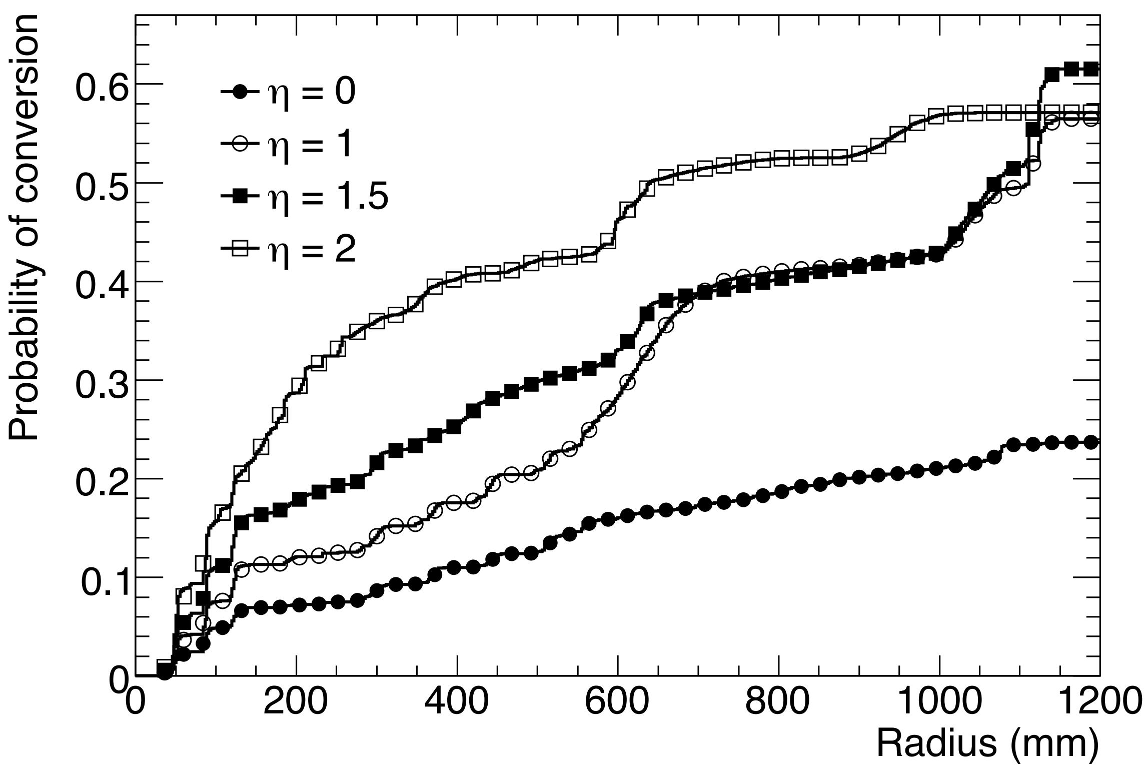


Figure 10.22: Probability for a photon to have converted as a function of radius for different values of $|\eta|$, shown for photons with $p_T > 1$ GeV in minimum-bias events. The probability is not a strong function of the photon energy.

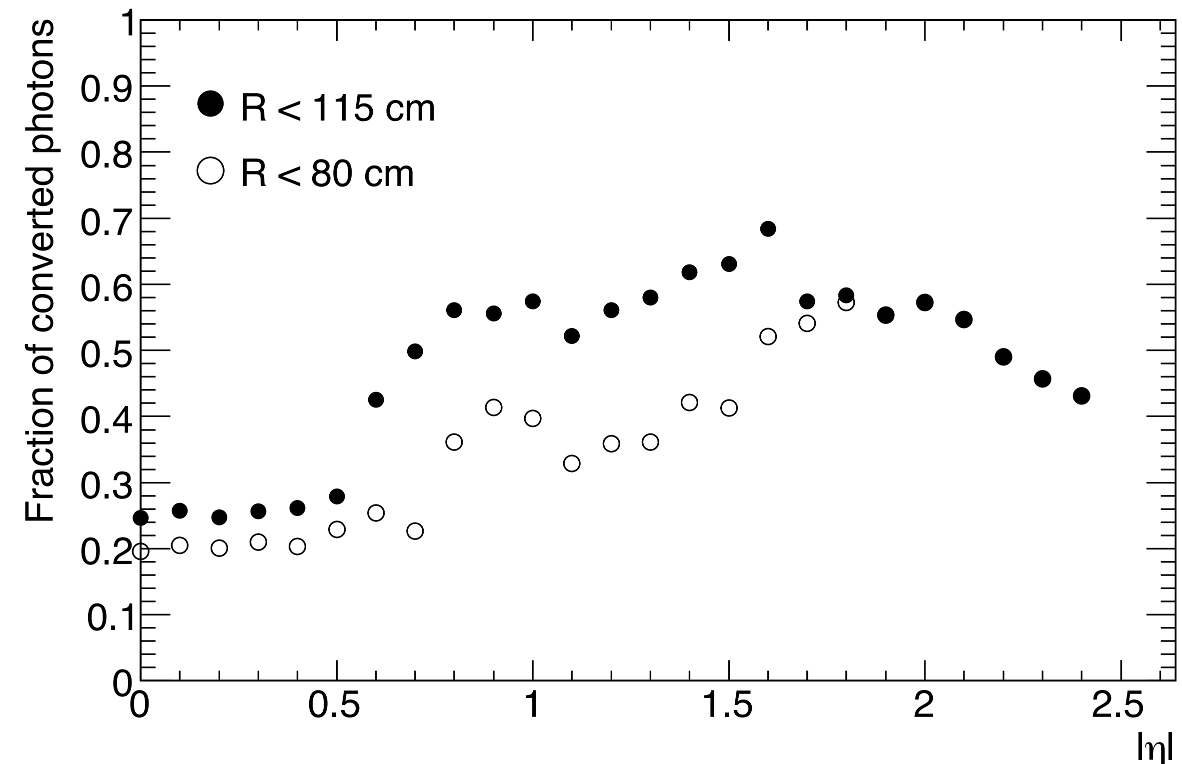
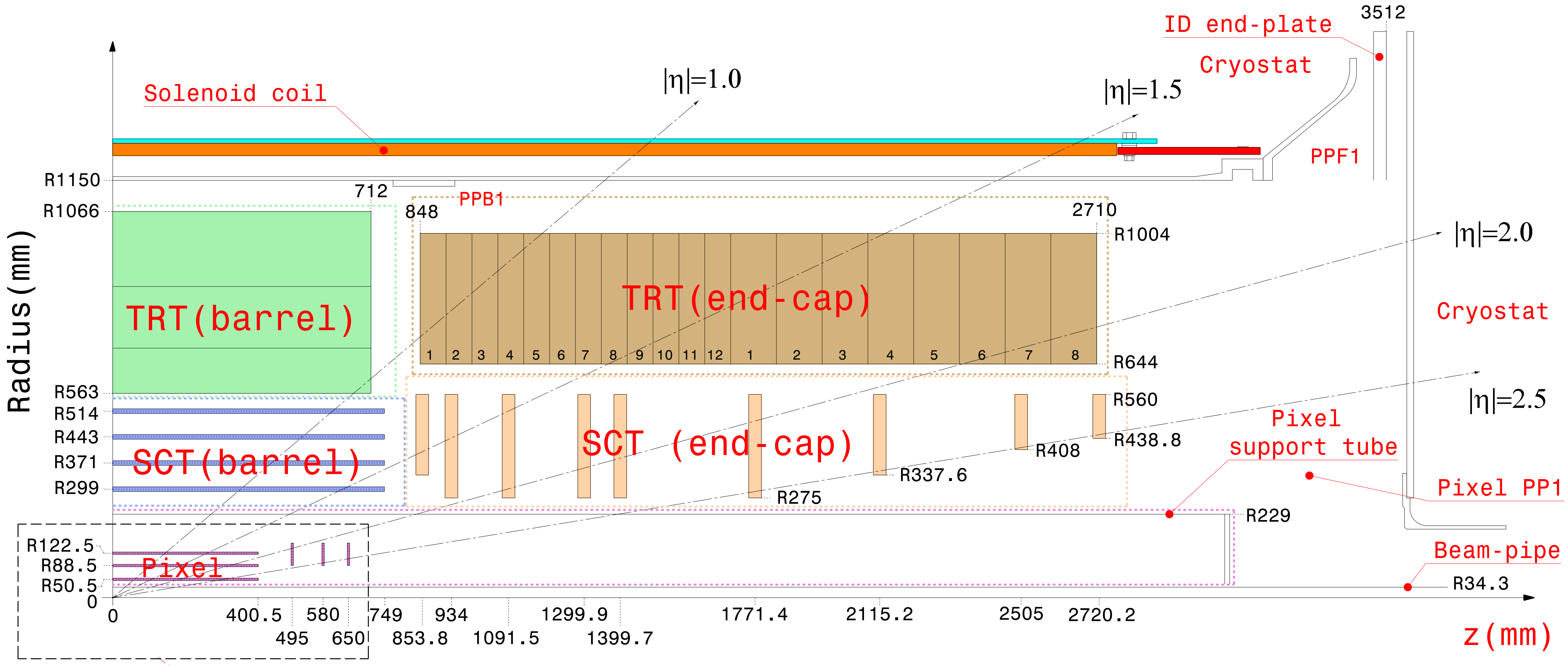
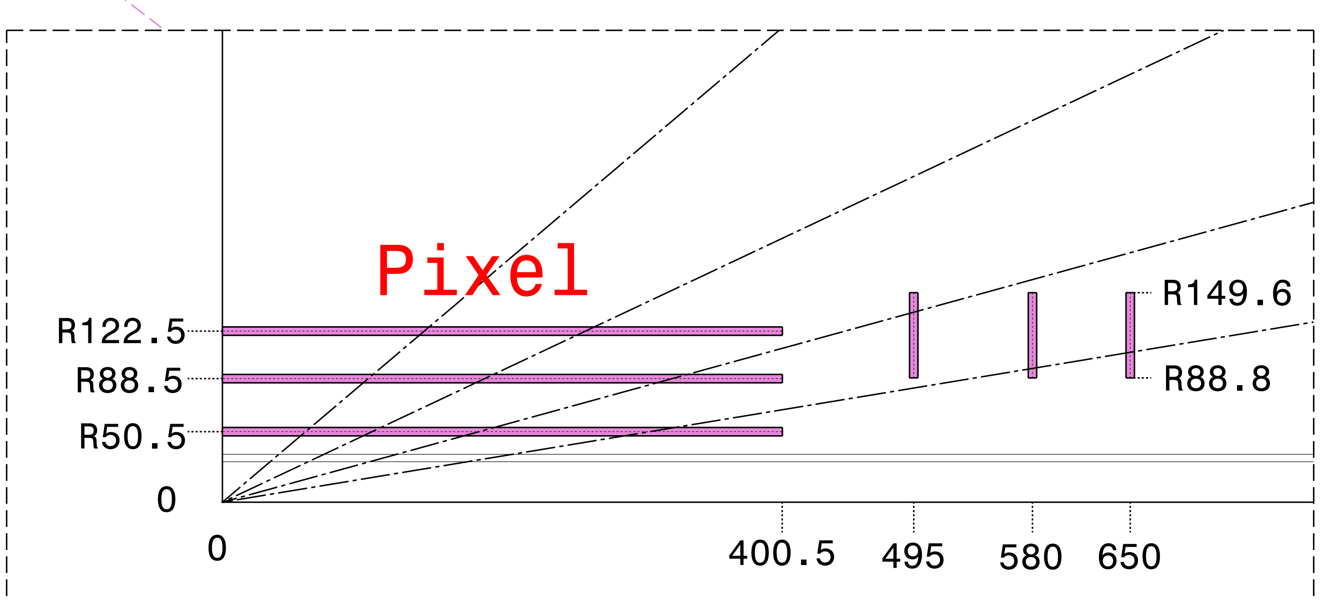


Figure 10.43: Fraction of photons converting at a radius of below 80 cm (115 cm) in open (full) circles as a function of $|\eta|$.

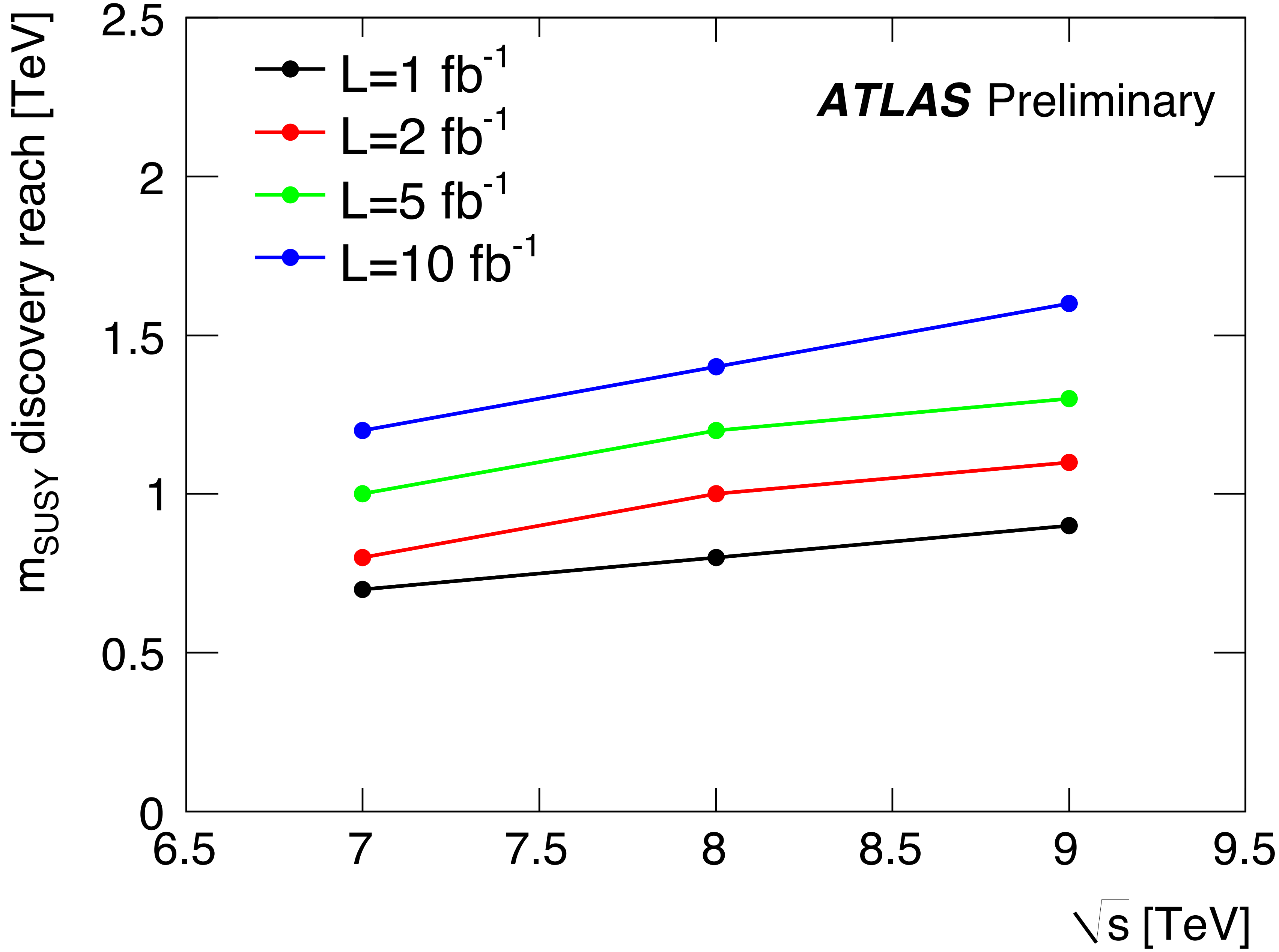




Envelopes

Pixel		45.5<R<242mm |Z|<3092mm
SCT barrel		255<R<549mm |Z|<805mm
SCT end-cap		251<R<610mm 810<|Z|<2797mm
TRT barrel		554<R<1082mm |Z|<780mm
TRT end-cap		617<R<1106mm 827<|Z|<2744mm

Discovery reach as a function of $\sqrt{s}$



GGM PDF and Scale Uncertainties

$m(\tilde{g})$ [GeV]	PDF	Scale	Total
400	0.12	0.16	0.20
500	0.15	0.17	0.22
550	0.17	0.18	0.24
600	0.18	0.18	0.25
650	0.19	0.18	0.26
700	0.21	0.18	0.27
750	0.23	0.19	0.30
800	0.25	0.19	0.31
850	0.27	0.20	0.33
900	0.29	0.20	0.35
1000	0.33	0.21	0.39
1100	0.38	0.22	0.44
1200	0.44	0.23	0.49