Revisiting the LHC Constraints on Gauge-Mediated Supersymmetry Breaking Scenarios

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(Re)Interpretation of the LHC results for new physics
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Motivation: Why This Study?

ATLAS Mono-Photon Search (JHEP07(2023)021)

Constraints the GMSB parameter space looking into a final state with at least one photon and large missing energy.

Fat-Brane mUED (Next Talk)

- Implement the ATLAS analysis and validate key results.
- Calculate the bounds on the model parameter space.

But Here's the Puzzle

Our attempt to validate the analysis showed discrepancies of 250-300 GeV in some regions.

The Key Issue: Gravitino Decays

ATLAS Assumption

Only the lightest neutralino decays into a gravitino is considered.

But Why?

The decay width calculations for neutralinos and charginos are similar!

What We Found

- This assumption holds in **60-70% of the parameter space**.
- The 7 and 8 TeV LHC searches focused on this regime.
- But at 13 TeV, the LHC is now probing regions where this assumption may not hold!

GMSB (Gauge Mediated SUSY Breaking)

The Phenomenological Model

- Extension of MSSM with ultralight gravitino ($\tilde{G}$).
- R-parity Conserved.

SUSY particle spectrum

- Sleptons/Squarks decouple at around 5 TeV.
- Extra Higgs sector decouple at around $2 - 2.5$ TeV.

Neutralinos and Charginos

- M_2 fixed at 3 TeV.
- $\tilde{\chi}_1^0 \to \tilde{G}\gamma / \tilde{G}Z / \tilde{G}h$
- The sign of μ decides the NLSP ($\tilde{\chi}_1^0$) decay BRs.

Key Parameters

- $|M_1| \approx |\mu|, |M_3|$.
- $m_{\tilde{G}} \sim 1$ eV $\to$ Prompt NLSP decay.

Collider Signature (with the ATLAS assumptions)

Key Factors

- Conserved R-parity
- Gluino production dominates

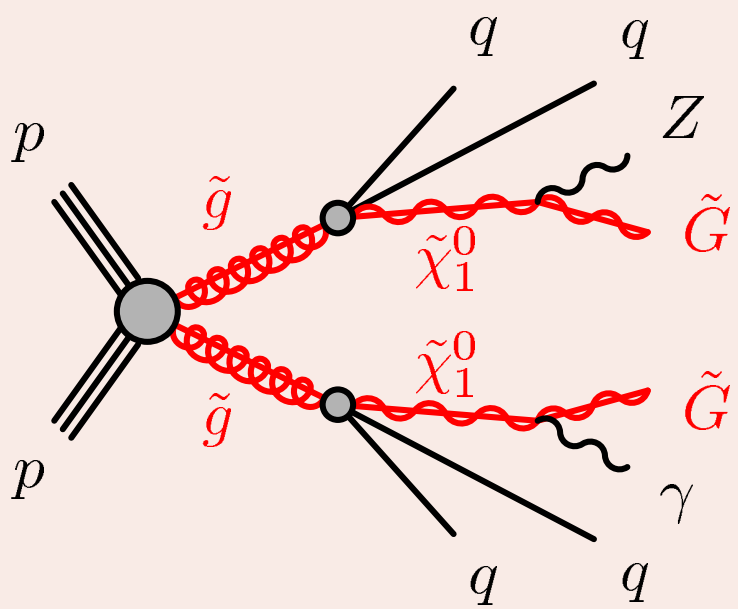
Decay Chain

Gluino $\rightarrow$ NLSP (neutralino) $\rightarrow$ LSP (gravitino)

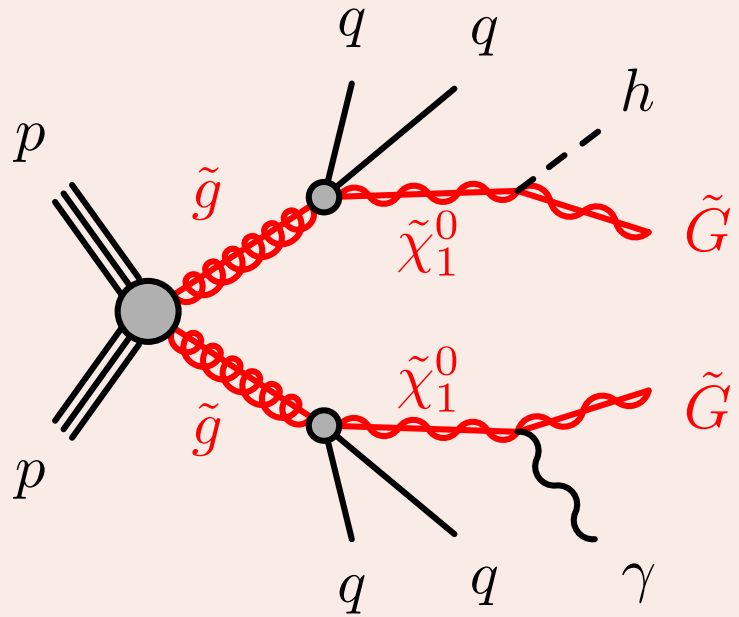
Signature

Multiple jets + MET + high-p_T photon

$\mu > 0$



$\mu < 0$



Decay of SUSY Particles

Neutralino Decay Widths

$$\Gamma(\tilde{\chi}_i^0 \to \gamma \tilde{G}) = \frac{k_{i\gamma}}{48\pi} \frac{m^5_{\tilde{\chi}_i^0}}{M_P^2 m^2_{\tilde{G}}},$$

$$\Gamma(\tilde{\chi}_i^0 \to Z \tilde{G}) = \frac{2k_{iZ_T} + k_{iZ_L}}{96\pi} \frac{m^5_{\tilde{\chi}_i^0}}{M_P^2 m^2_{\tilde{G}}} \left(1 - \frac{m_Z^2}{m^2_{\tilde{\chi}_i^0}}\right)^4,$$

$$\Gamma(\tilde{\chi}_i^0 \to h \tilde{G}) = \frac{k_{ih}}{96\pi} \frac{m^5_{\tilde{\chi}_i^0}}{M_P^2 m^2_{\tilde{G}}} \left(1 - \frac{m_h^2}{m^2_{\tilde{\chi}_i^0}}\right)^4.$$

Couplings

$$k_{i\gamma} = |N_{i1} c_w + N_{i2} s_w|^2,$$
$$k_{iZ_T} = |N_{i1} s_w - N_{i2} c_w|^2,$$
$$k_{iZ_L} = |N_{i3} c_\beta - N_{i4} s_\beta|^2,$$
$$k_{ih} = |N_{i3} s_\alpha - N_{i4} c_\alpha|^2.$$

Chargino Decay Width

$$\Gamma(\tilde{\chi}_i^+ \to W^+ \tilde{G}) = \frac{2k_{iW_T} + k_{iW_L}}{96\pi} \frac{m^5_{\tilde{\chi}_i^+}}{M_P^2 m^2_{\tilde{G}}} \left(1 - \frac{m_w^2}{m^2_{\tilde{\chi}_i^+}}\right)^4$$

Couplings

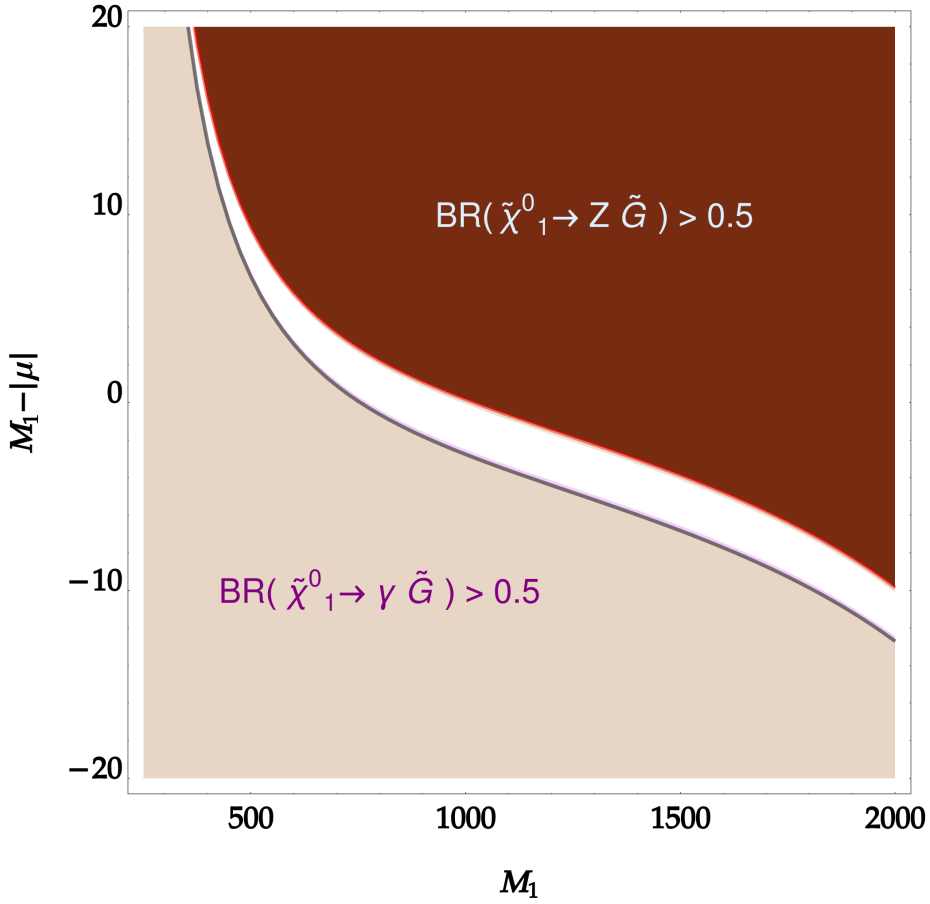
$$k_{iW_T} = \tfrac{1}{2}(|V_{i1}|^2 + |U_{i1}|^2),$$
$$k_{iW_L} = |V_{i2}|^2 s_\beta^2 + |U_{i2}|^2 c_\beta^2.$$

Gluino Decay Width

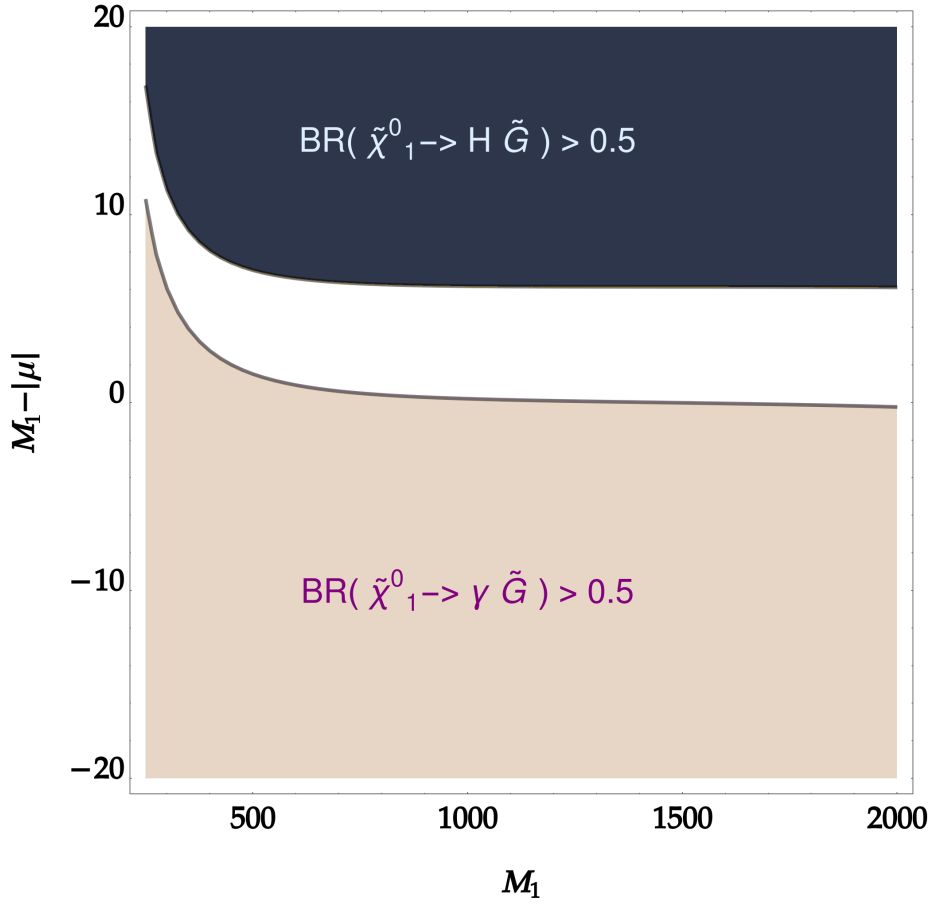
$$\Gamma(\tilde{g} \to g \tilde{G}) = \frac{m^5_{\tilde{g}}}{48\pi M_P^2 m^2_{\tilde{G}}}$$

$\tilde{\chi}_1^0$ Decay Phase Diagram

$(\mu > 0)$

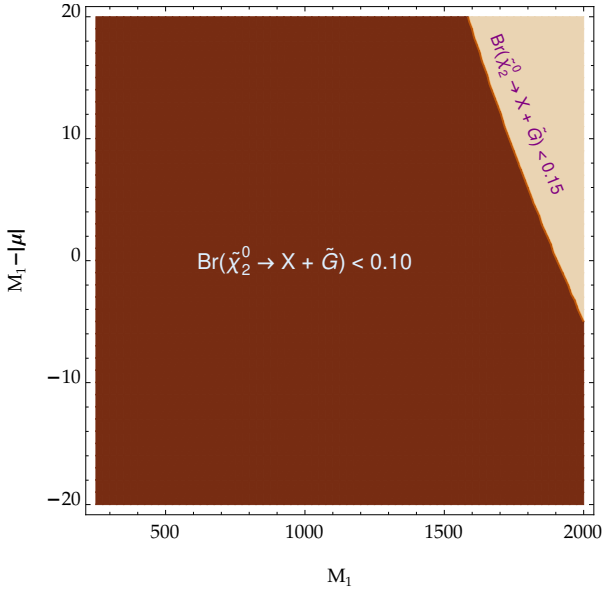


$(\mu < 0)$

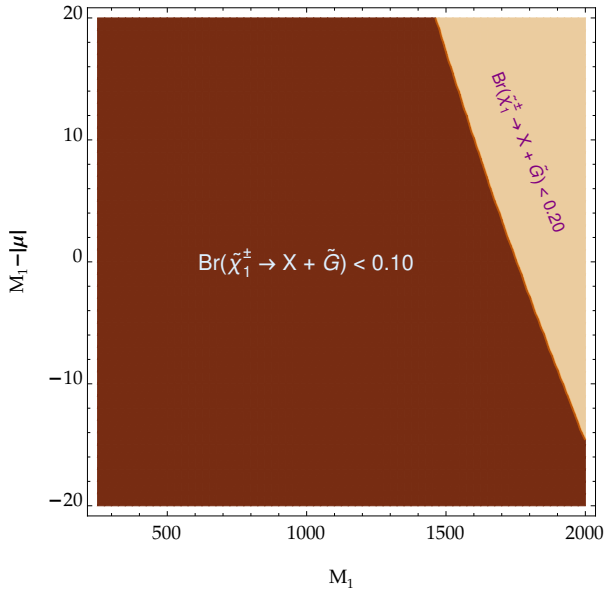


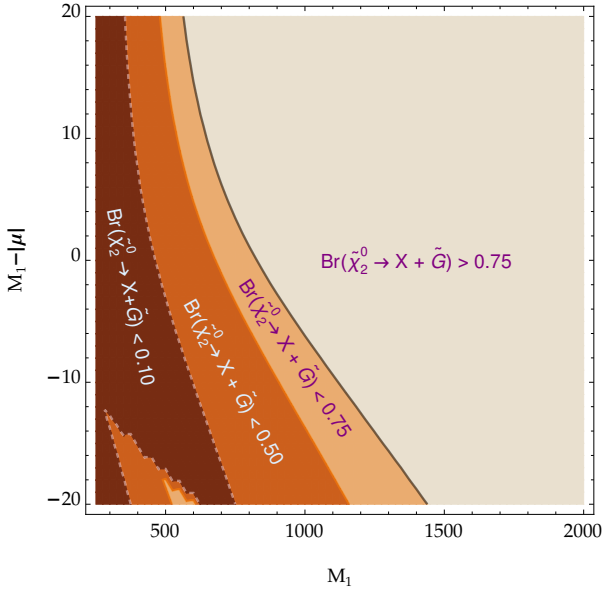
Decay of other SUSY particles

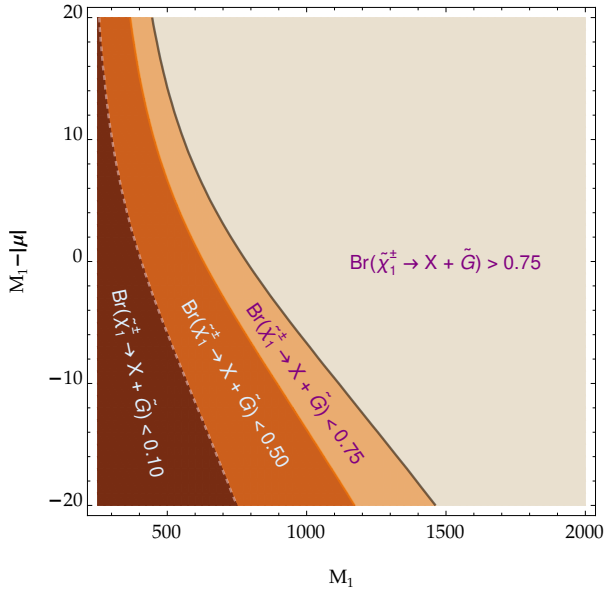
$(\tilde{\chi}_2^0)$



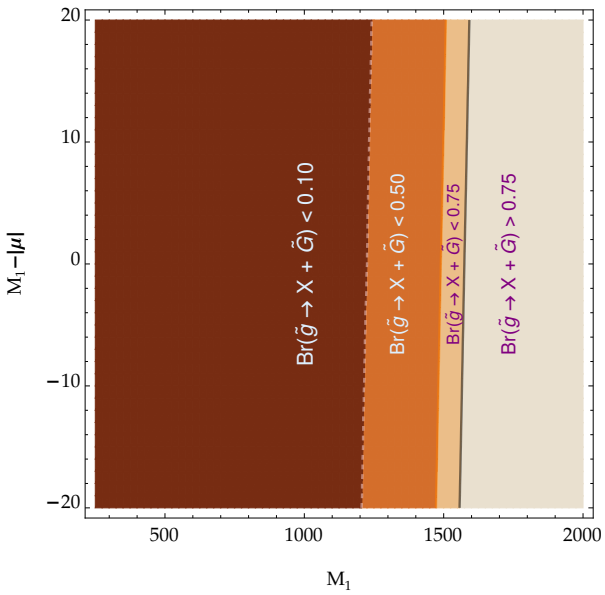
$(\tilde{\chi}_1^\pm)$







$(\tilde{g})$



Collider Phenomenology

Tools Used

SARAH $\rightarrow$ SPheno $\rightarrow$ MG5_AMC@NLO $\rightarrow$ Pythia8 $\rightarrow$ Delphes (ATLAS card)

SM Backgrounds

Dominant Backgrounds: $t\bar{t}\gamma,\ W/Z\gamma, \gamma j, \gamma jj, \gamma\gamma j$

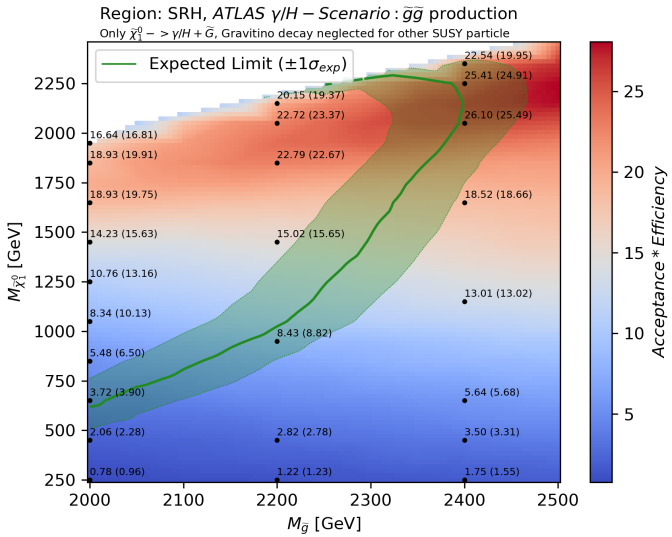
Background information $\rightarrow$ ATLAS paper and HEPData.

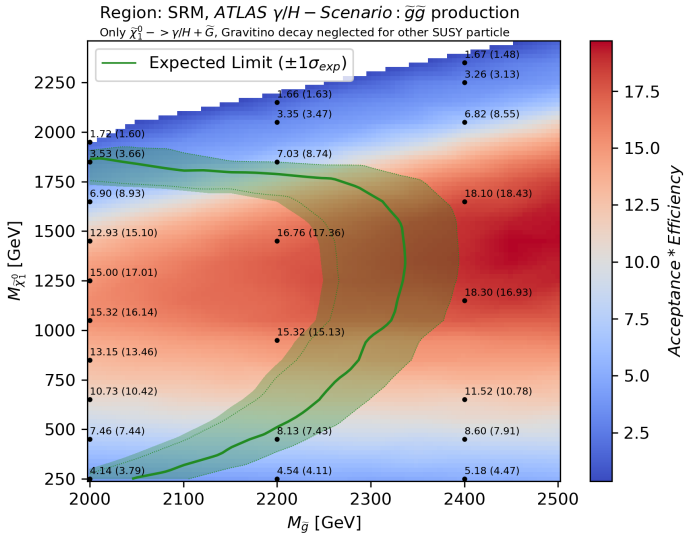
Object Reconstruction and Event Selection

Three Signal Regions: SRL, SRM, SRH

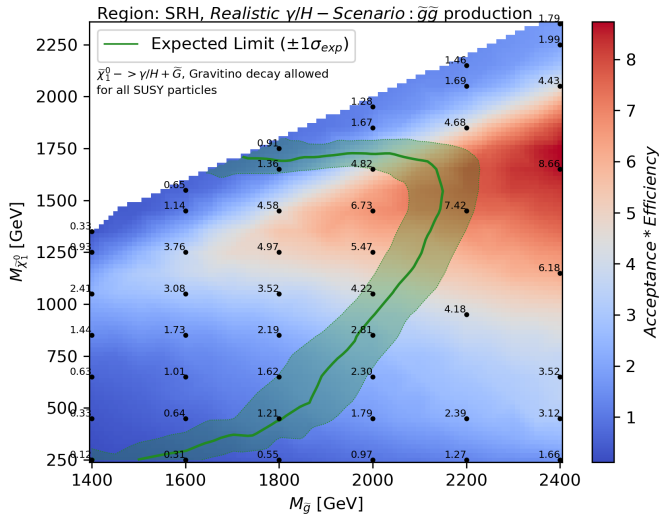
Validation and Results

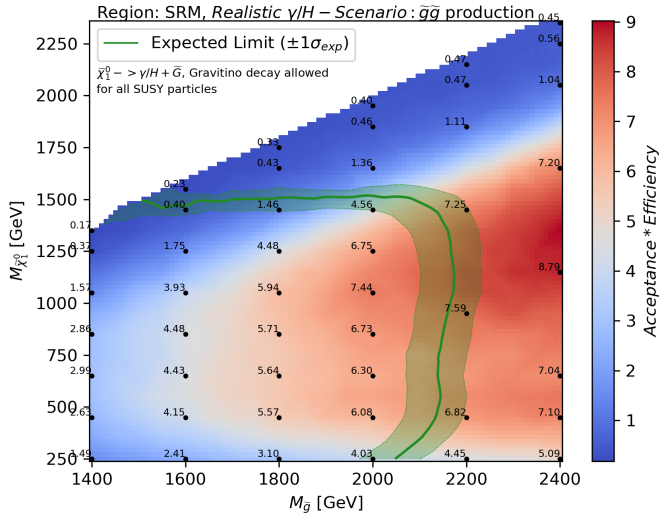
(ATLAS Scenario)



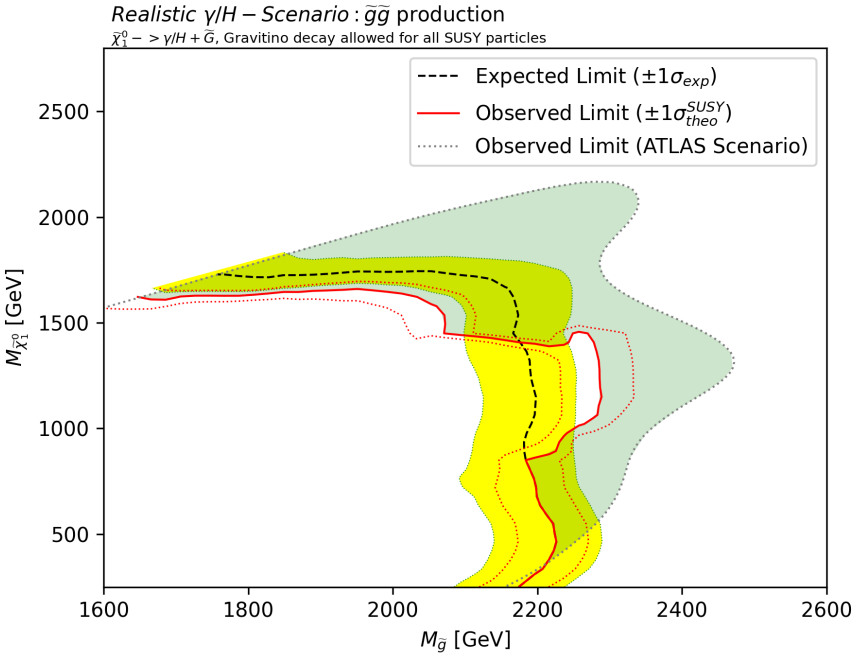


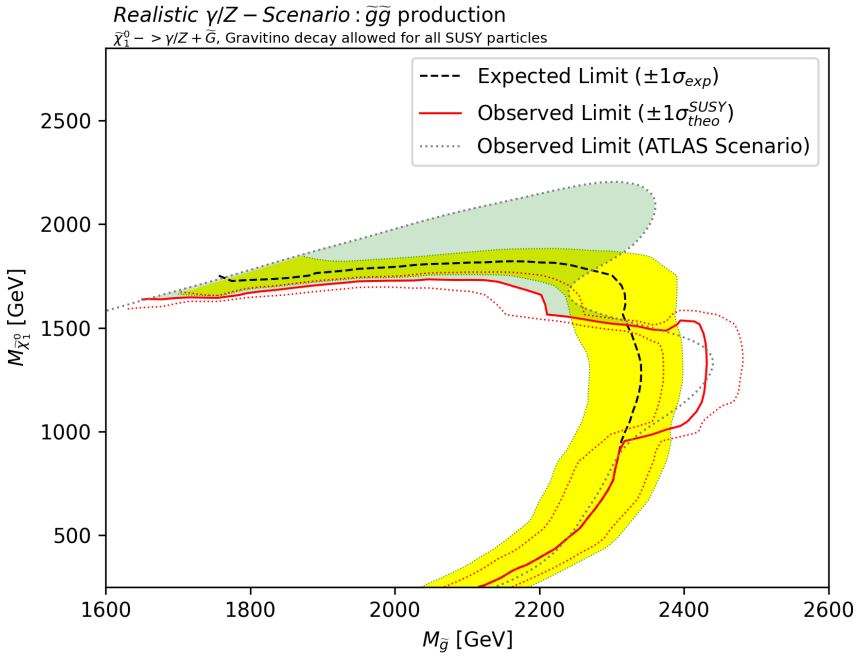
(Full GMSB model)





Final Results





Final Results

Quasi-degenerate gluino NLSP-neutralino region:

- SRH signal region targets compressed spectra ($\Delta M = M_{\tilde{g}} - M_{\tilde{\chi}_1^0}$).
- For small ΔM, gravitino decays dominate over cascade decays.
- Leads to **relaxed bounds** in this region.

Regions where gravitino decay modes for $\tilde{\chi}_2^0, \tilde{\chi}_3^0$, and $\tilde{\chi}_1^\pm$ dominate:

- Significant for **negative μ** scenario.
- Direct decays to gravitino suppress mono-photon final states.
- Reduces **gluino mass reach** in realistic GGM scenario.

Thank You!

Questions? Feel free to ask!

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Backpu Slides

The Model

- MSSM extension with a light gravitino: Gauge Mediated SUSY Breaking (GMSB) and its generalization, General Gauge Mediation (GGM).
- Messenger fields couple the visible and hidden sectors via SM gauge interactions.
- Flavor blindness of gauge interactions avoids the SUSY flavor problem.
- Soft breaking masses: $\langle F \rangle / M_{mess}$.
- Local SUSY breaking $\rightarrow$ goldstino absorbed by gravitino $\rightarrow$ $m_{\tilde{G}} \approx \langle F \rangle / M_P$.
- Gravitino mass suppressed by M_{mess}/M_P, making it the LSP in GMSB models.
- The sleptons and squarks are decoupled at 5 TeV.
- The Higgs sector, apart from the SM Higgs, decouples at around 2 TeV.
- A gravitino mass ~ 1 eV to allow prompt decay of the NLSP.
- The phenomenological model has two independent parameters $|M_1| \approx |\mu|$ and $|M_3|$.

Object Reconstruction

- **Photon Selection**: $p_T > 50$ GeV, $|\eta| < 2.37$, avoiding ECAL transition ($1.37 < |\eta| < 1.52$).
- **Isolation Criteria**:
  - **Calorimetric isolation**: $E_T^{\text{iso}} < 2.45\ \text{GeV} + 0.022\ p_T$.
  - **Track isolation**: $p_T^{\text{iso}} < 0.05\ p_T$.
- **Electron Selection**: $p_T > 25$ GeV, $|\eta| < 2.47$, 'loose' isolation, avoiding ECAL transition.
- **Muon Selection**: $p_T > 25$ GeV, $|\eta| < 2.7$, 'loose' isolation.
- **Jet Reconstruction**: Anti-k_t algorithm ($R = 0.4$), $p_T > 30$ GeV, $|\eta| < 2.5$.
- **Missing Transverse Momentum**: Computed from the vector sum of reconstructed objects and unassociated tracks.
- **Overlap Removal**: Applied to avoid double counting of selected objects.

Event Selection

The table presents the cuts used by the ATLAS analysis to define the three signal regions along with the model-independent 95 % Confidence Level upper bound on the visible cross-section.

	SRL	SRM	SRH
$N_{photons}$	≥ 1	≥ 1	≥ 1
$p_T^{leading-\gamma}$	> 145 GeV	> 300 GeV	> 400 GeV
$N_{leptons}$	0	0	0
N_{jets}	≥ 5	≥ 5	≥ 3
$\Delta\phi(jet, E_T^{miss})$	> 0.4	> 0.4	> 0.4
$\Delta\phi(\gamma, E_T^{miss})$	> 0.4	> 0.4	> 0.4
E_T^{miss}	> 250 GeV	> 300 GeV	> 600 GeV
H_T	> 2000 GeV	> 1600 GeV	> 1600 GeV
R_T^4	< 0.90	< 0.90	-
$\langle\epsilon\sigma\rangle_{obs}^{95}$(fb)	0.034	0.022	0.054