Physics

ie Mellon University

Search for supersymmetry in events with photons at CMS

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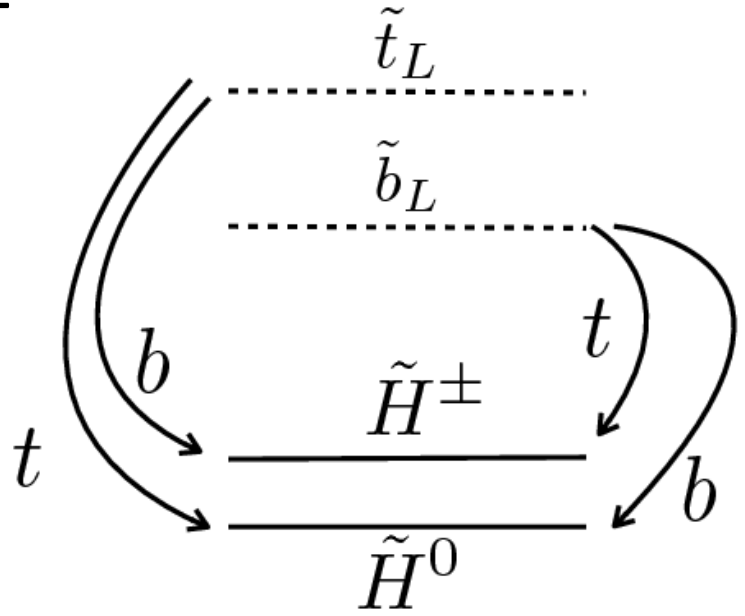
Introduction

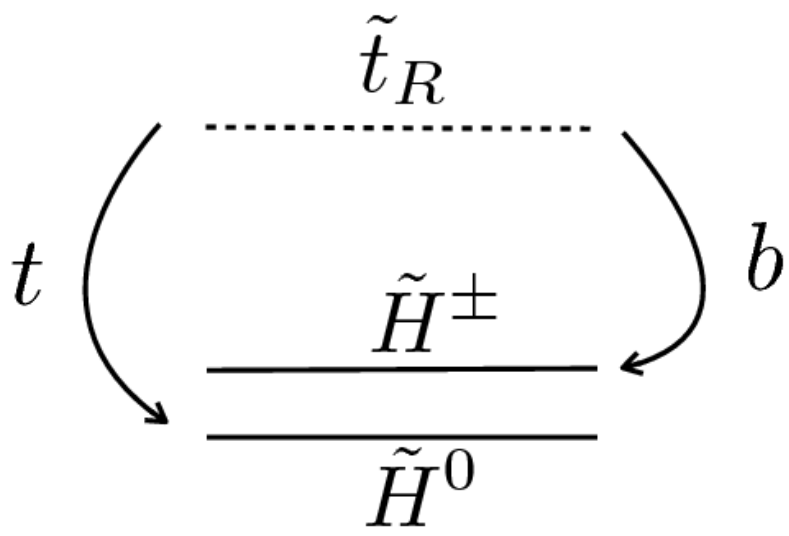
- ☑ Discover new boson consistent with Higgs
  - ☑ Confirm boson is Higgs
- ❑ Hierarchy problem: Why is Higgs so much lighter than apparent unification scale (Planck mass)?
- ❑ Gauge coupling unification
- ❑ Dark matter: Stable, massive, weakly interacting

- SUSY appears as potential answer to each question
  - Gauge mediation one of the simplest, most robust breaking mechanisms
  - Gravitino LSP and (usually) photons from bino-like NLSP

Razor $H \rightarrow \gamma\gamma$ (SUS-16-045)

- Higgs bosons can result from a wide range of SUSY decays
  - Most models also involve large hadronic energy (from strongly produced SUSY particles) and missing energy (from stable LSPs)
- Many possible scenarios: Motivates an inclusive search for anomalous Higgs production at high H_T, MET
- $H \rightarrow \gamma\gamma$ is among most accessible channels due to suppression of backgrounds



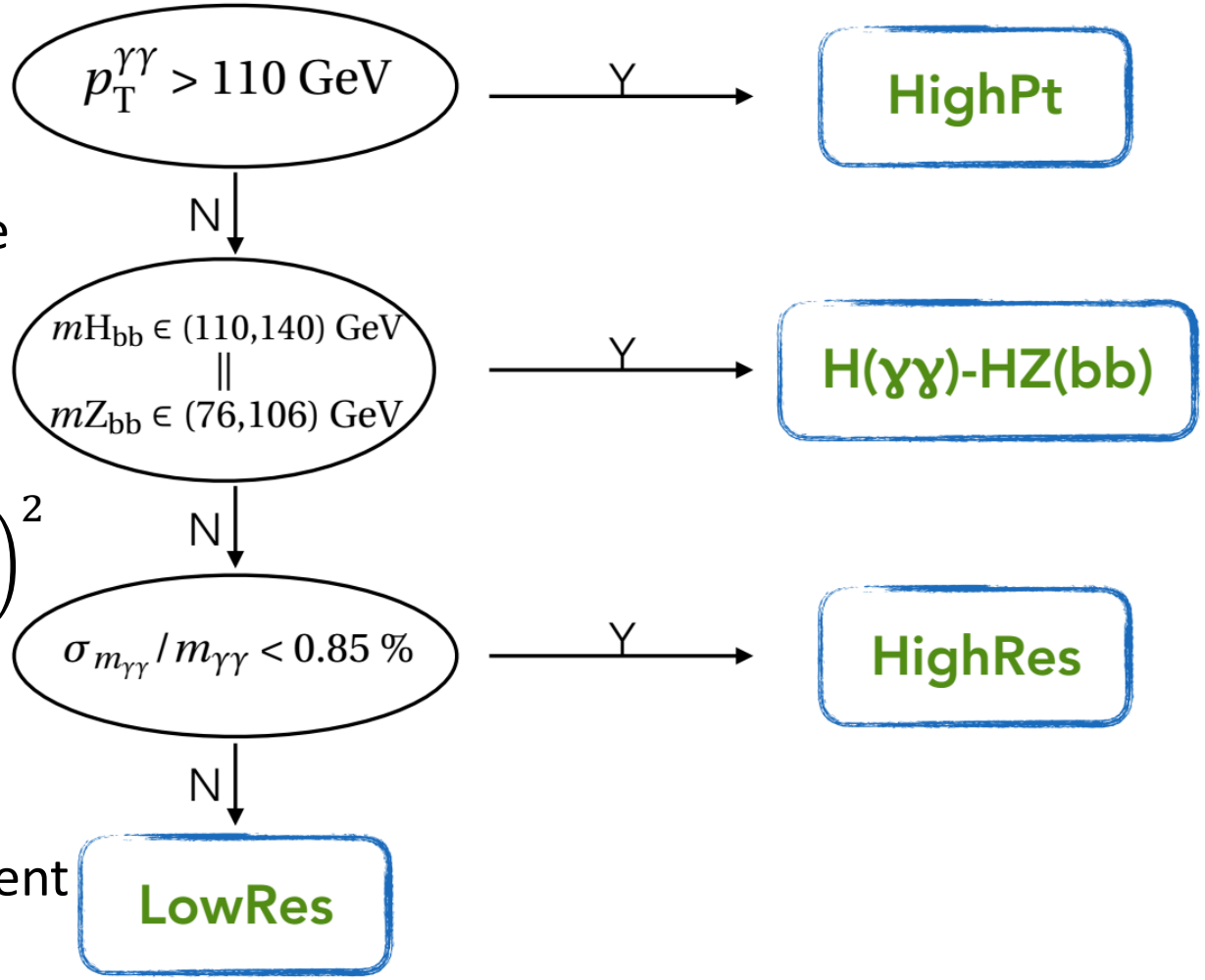


Event categorization

- Select Higgs candidate
  - 2 high-pT barrel photons with $103 < M_{\gamma\gamma} < 160$ GeV
  - $M_{\gamma\gamma}$ used as discriminant / background estimate
- Compute razor variables
  - At least 1 high-p_T jet for razor variables
  - Compute jet hemispheres j1 and j2

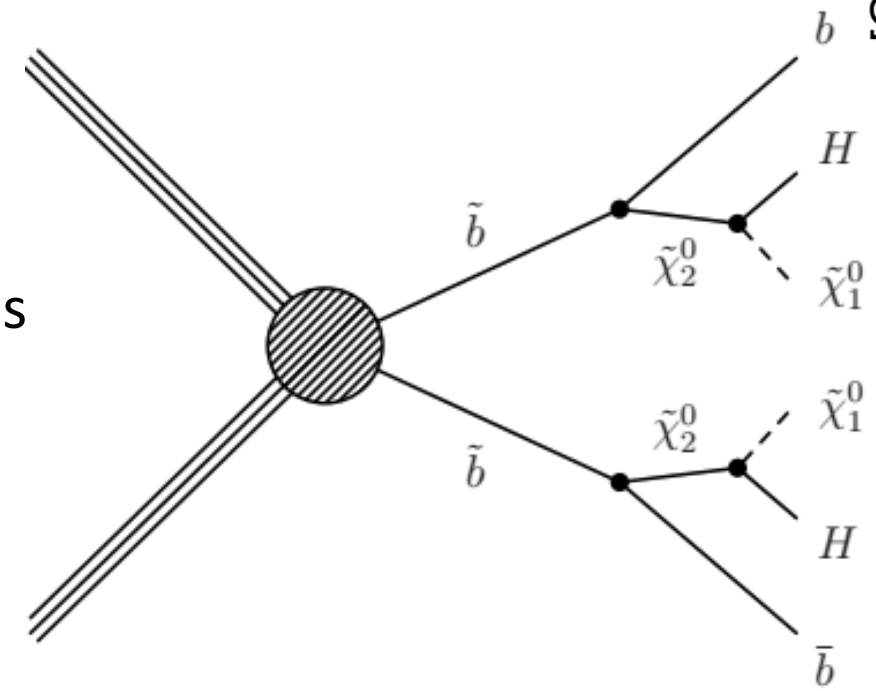
$$M_R \equiv \sqrt{(p^{j1} + p^{j2})^2 - \left(p_z^{j1} + p_z^{j2}\right)^2}, R^2 \equiv \left(\frac{M_T^R}{M_R}\right)^2$$

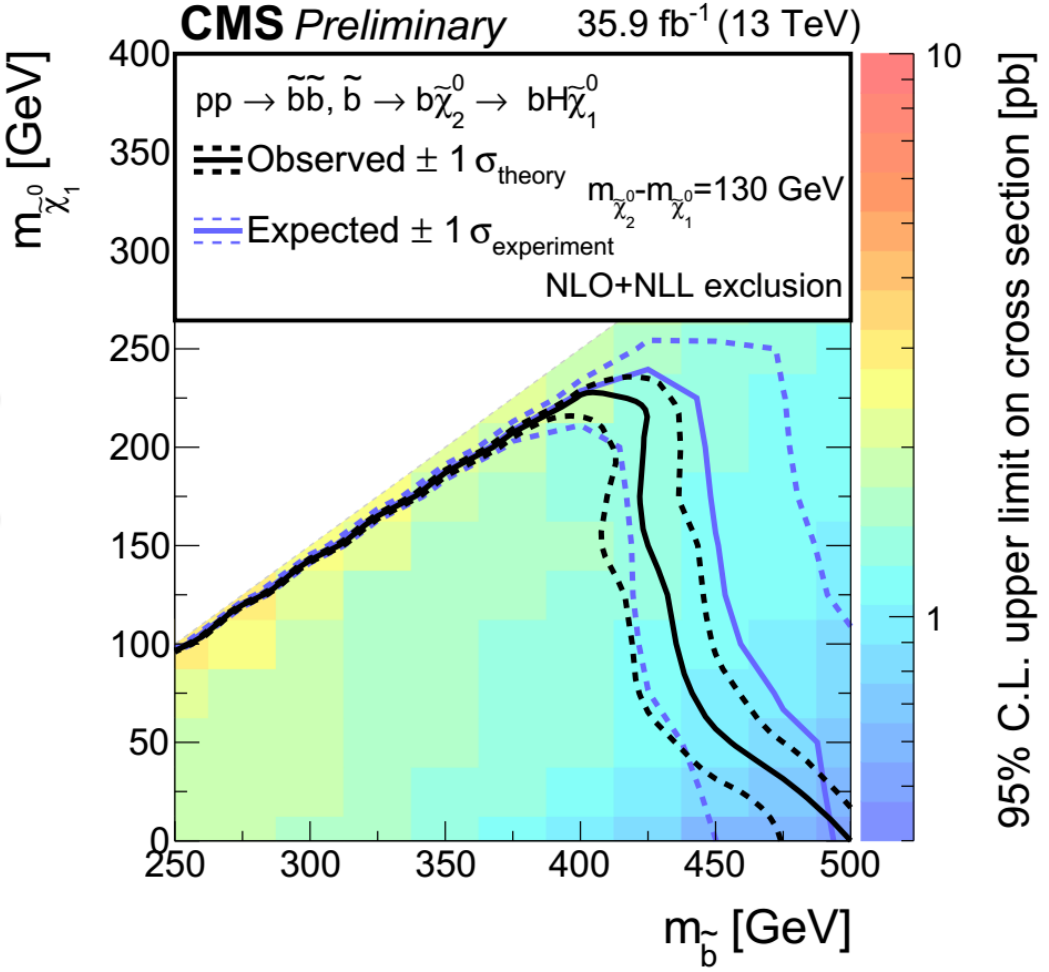
- Categorize events to maximize signal-to-background discrimination
  - SUSY signals often involve additional Higgs or Z
  - High resolution category for generic enhancement of Higgs over non-resonant background



Limits on sbottom model

- Improvement in sensitivity over previous result
  - Strong sensitivity even at low neutralino masses



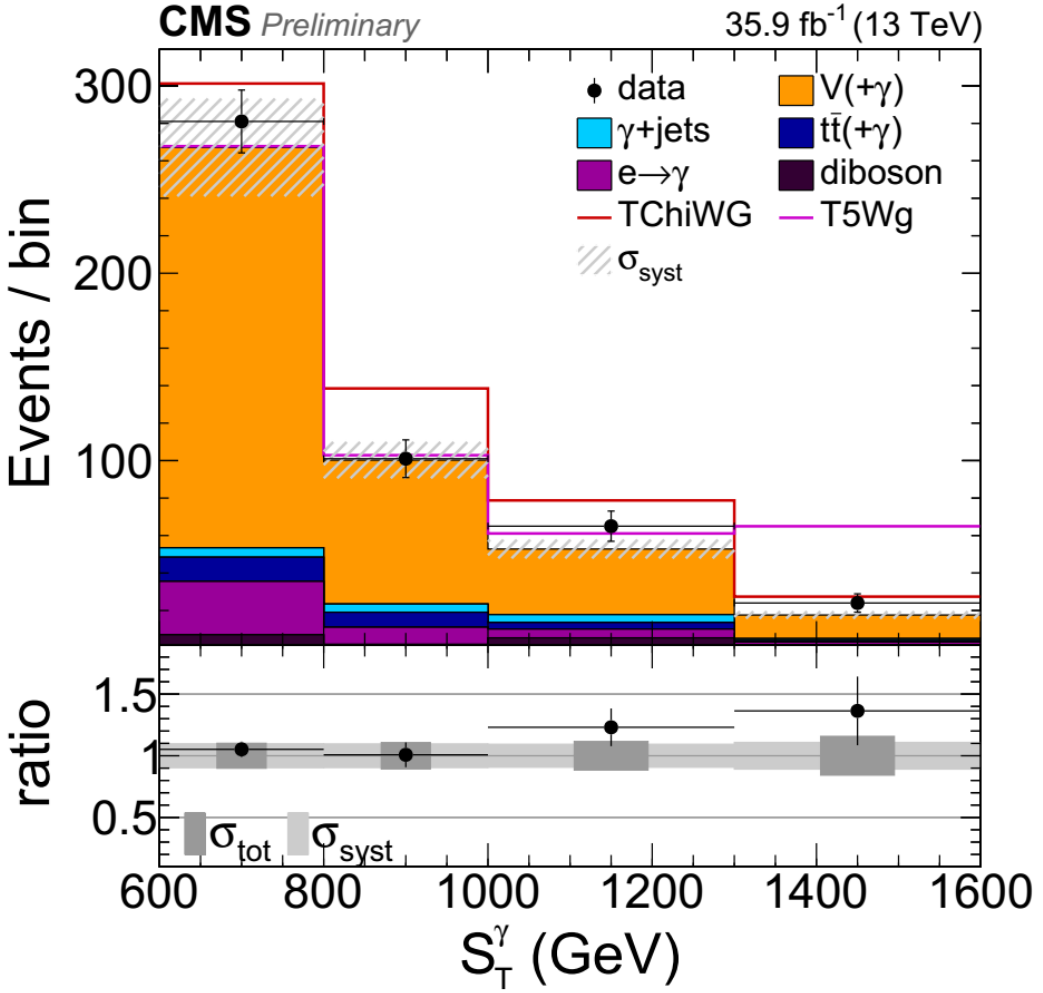


Photon + p_T^{miss} (SUS-16-046)

- Gauge mediated supersymmetry breaking (GMSB)
  - Gravitino $\tilde{G}$ lightest SUSY particle (LSP), stable
  - Lightest neutralino $\tilde{\chi}_1^0$ next-to-lightest SUSY particle (NLSP), prompt decay
  - Bino-like neutralino decays with high probability to $\gamma + \tilde{G}$
- Properties of the final states:
  - At least one high-p_T photon
    - Require $p_T^{\gamma} > 180$ GeV
  - Significant missing transverse momentum p_T^{miss} from stable LSP
    - $p_T^{miss} > 300$ GeV, $M_T\left(\gamma, p_T^{miss}\right) > 300$ GeV
  - Hadronic jet activity H_T depends on production mechanism
    - No requirements on leptons, jets, or H_T

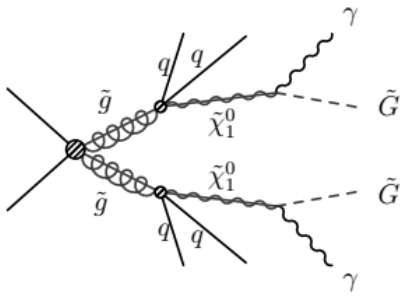
Signal region

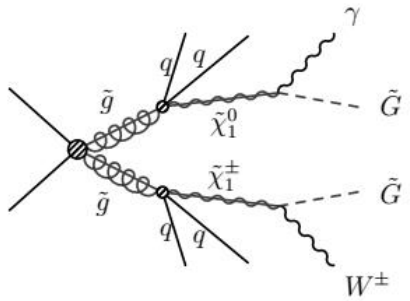
- Divided into 4 exclusive regions based on S_T^γ
- Use simplified SUSY models
  - TChiWg: Ewk production, assumes mass-degenerate $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ co-NLSPs
  - T5Wg: Gluino production to ewkinos
- Signal shown stacked with background contributions
  - Take TChiWG $M_{\tilde{\chi}} = 700$ GeV
  - Take T5Wg $M_{\tilde{g}} = 1750$ GeV, $M_{\tilde{\chi}} = 1700$ GeV
- Signal contamination accounted for in limit
  - Negligible in all non-excluded phase space

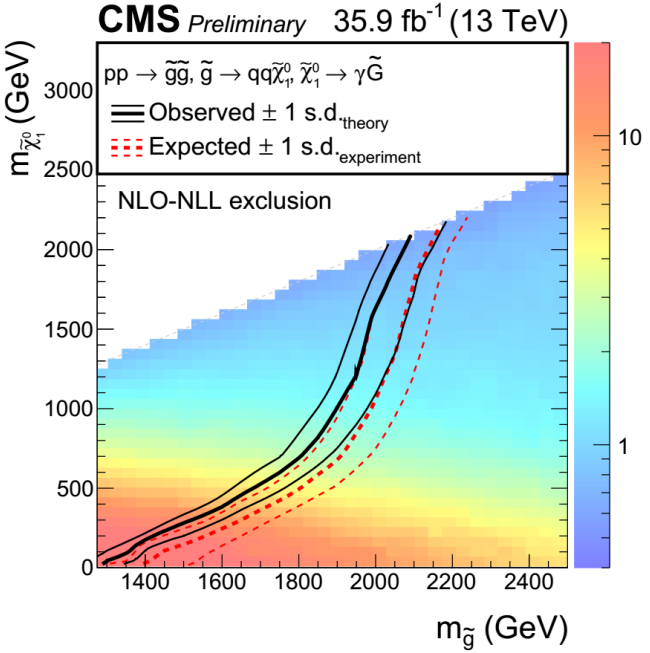


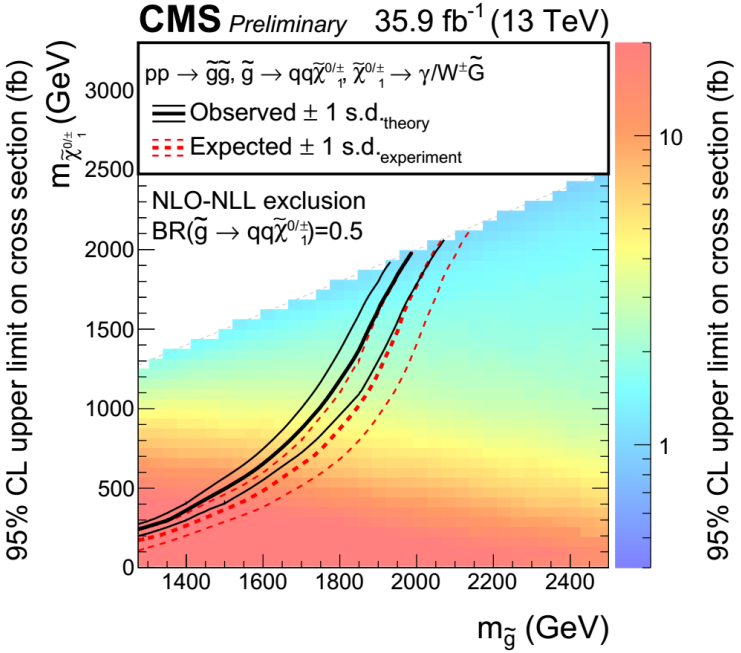
Interpretation (strong production models)

- T5gg and T5Wg simplified SUSY models
  - T5Wg cross section assumes mass-degenerate $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ co-NLSPs
  - Can exclude gluino masses up to 2.1 and 2.0 TeV respectively
    - Weaker limit at low neutralino mass







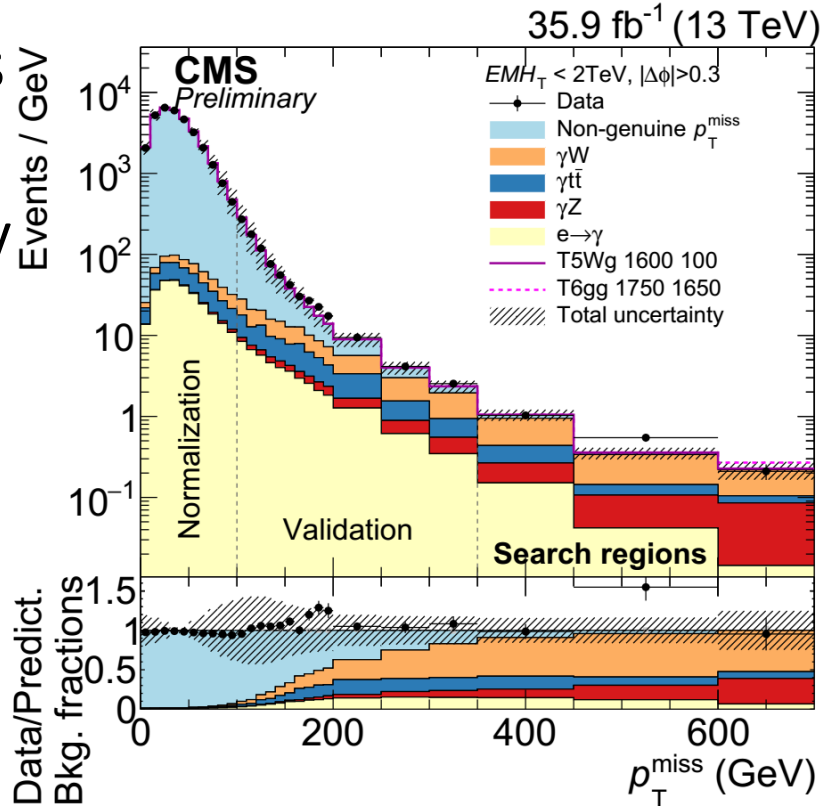


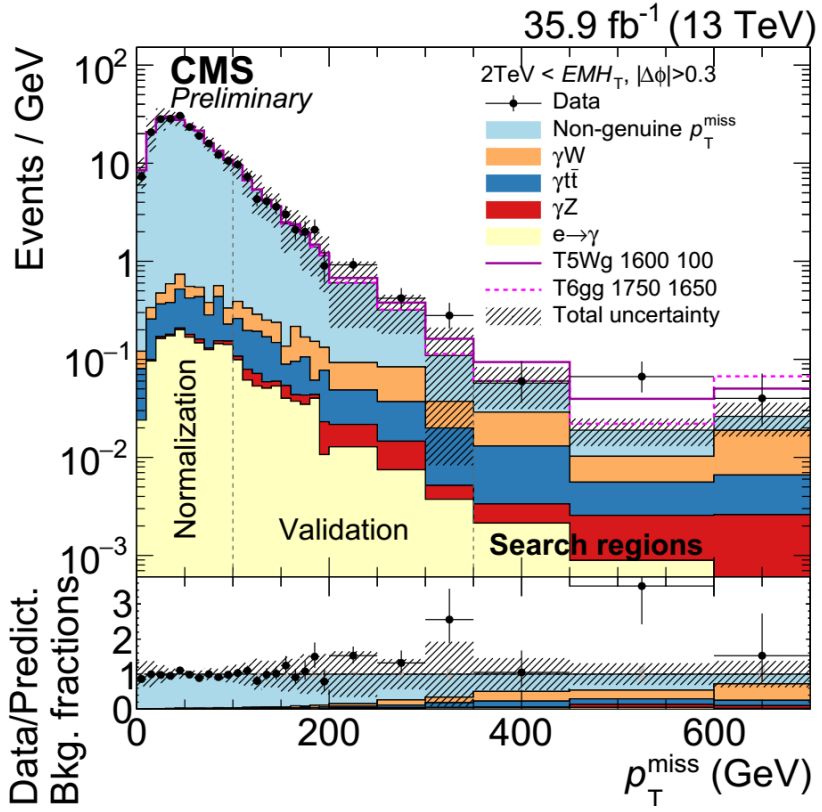
Photon + EMH_T + p_T^{miss} (SUS-16-047)

- Gauge mediated SUSY
  - Gravitino $\tilde{G}$ LSP, stable
  - Lightest neutralino $\tilde{\chi}_1^0$ NLSP, prompt decay
  - Allow chargino $\tilde{\chi}_1^{\pm}$ co-NLSP
  - Assume strong (squark or gluino) production
- Properties of the final states:
  - At least one high-p_T, central photon
    - Require $p_T^{\gamma} > 100$ GeV
  - Significant missing transverse momentum p_T^{miss} from stable LSP
    - $p_T^{miss} > 350$ GeV
  - Significant transverse energy EMH_T from jets and photon
    - $EMH_T = \sum_i p_T^{ji} + p_T^{\gamma} > 700$ GeV

Signal region

- Divided into exclusive regions based on EMH_T and p_T^{miss}
- Signal shown stacked with background contributions
- See definite (local) excess in next-to-last bins
  - 2.3σ and 2.2σ respectively





Interpretation for strong production models

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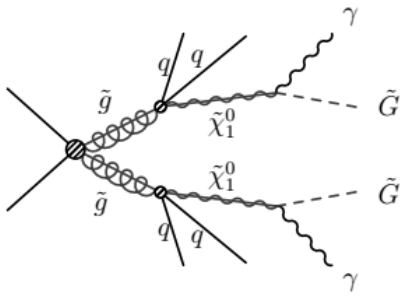
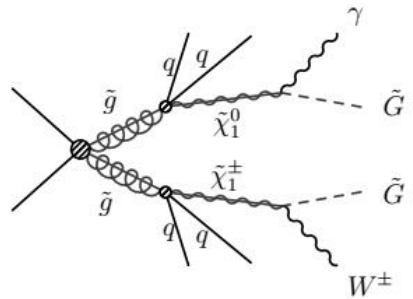
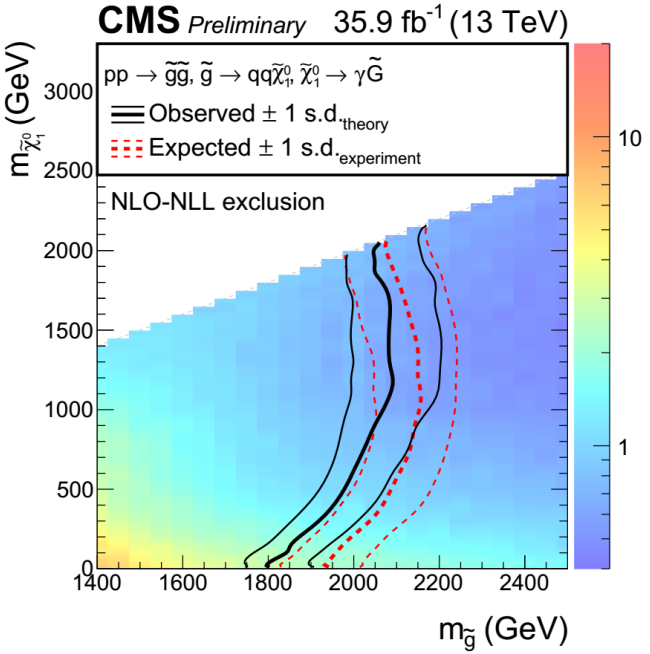
- Similar expected and observed limits at high gaugino masses
  - Effect dominated by agreement in bin
- Less sensitivity in T5Wg for $M_{\tilde{\chi}} \approx M_W$ due to on-shell W production







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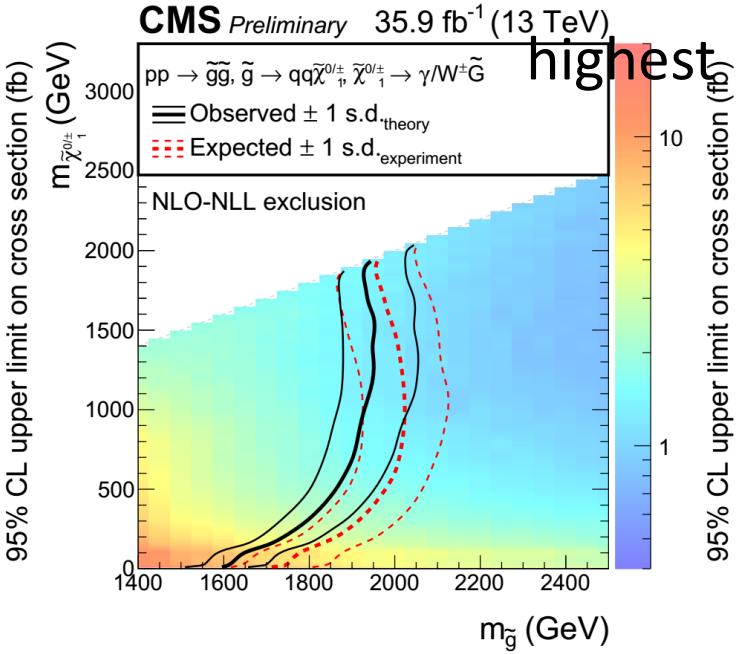


Conclusions

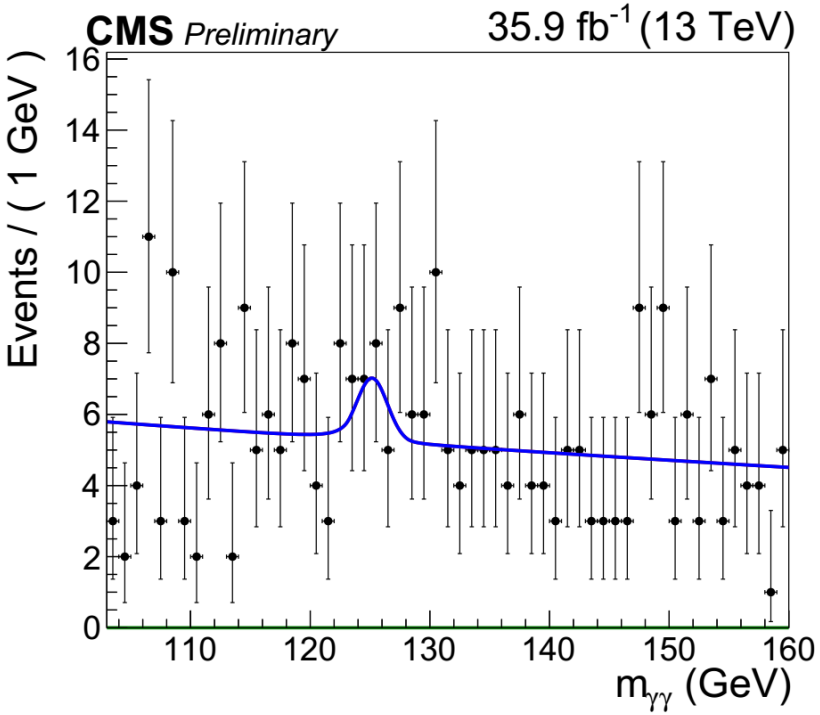
- No evidence of SUSY in photon channels yet
  - Interesting hints in some regions, at local 2σ level
- SUSY provides excellent framework for studying a large variety of final states across range of mass hierarchies
- Strong (and growing) program of photon-inspired SUSY searches at CMS
  - Many powerful searches in photon final states covering very large phase space
  - Higher luminosities could lead to new innovations
    - Final states with photons and b jets
    - Long-lived scenarios
    - Stealth scenarios
    - …

Backup

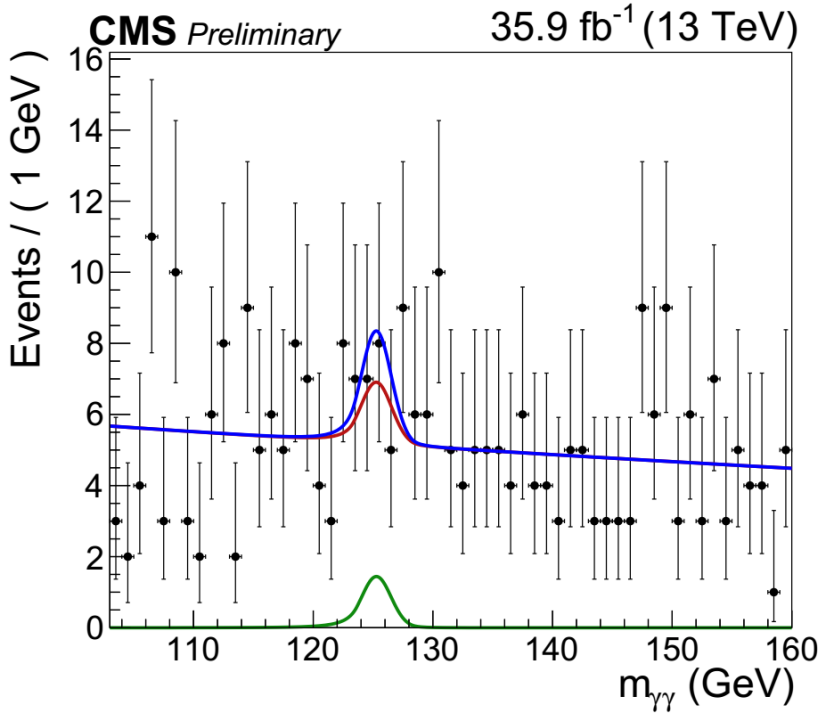
SUS-16-045 results: High-p_T region

- Single exponential fit to non-resonant background
- Double-sided crystal ball fitted to MC simulation used for both SM Higgs and SUSY signal
- 35.9 fb^{-1}: High-p_T, $M_R > 600$ GeV, $R^2 > 0.025$
- $N_S = 4.8 \pm 6.3 \rightarrow 0.7\sigma$

Background-only fit (includes SM Higgs)

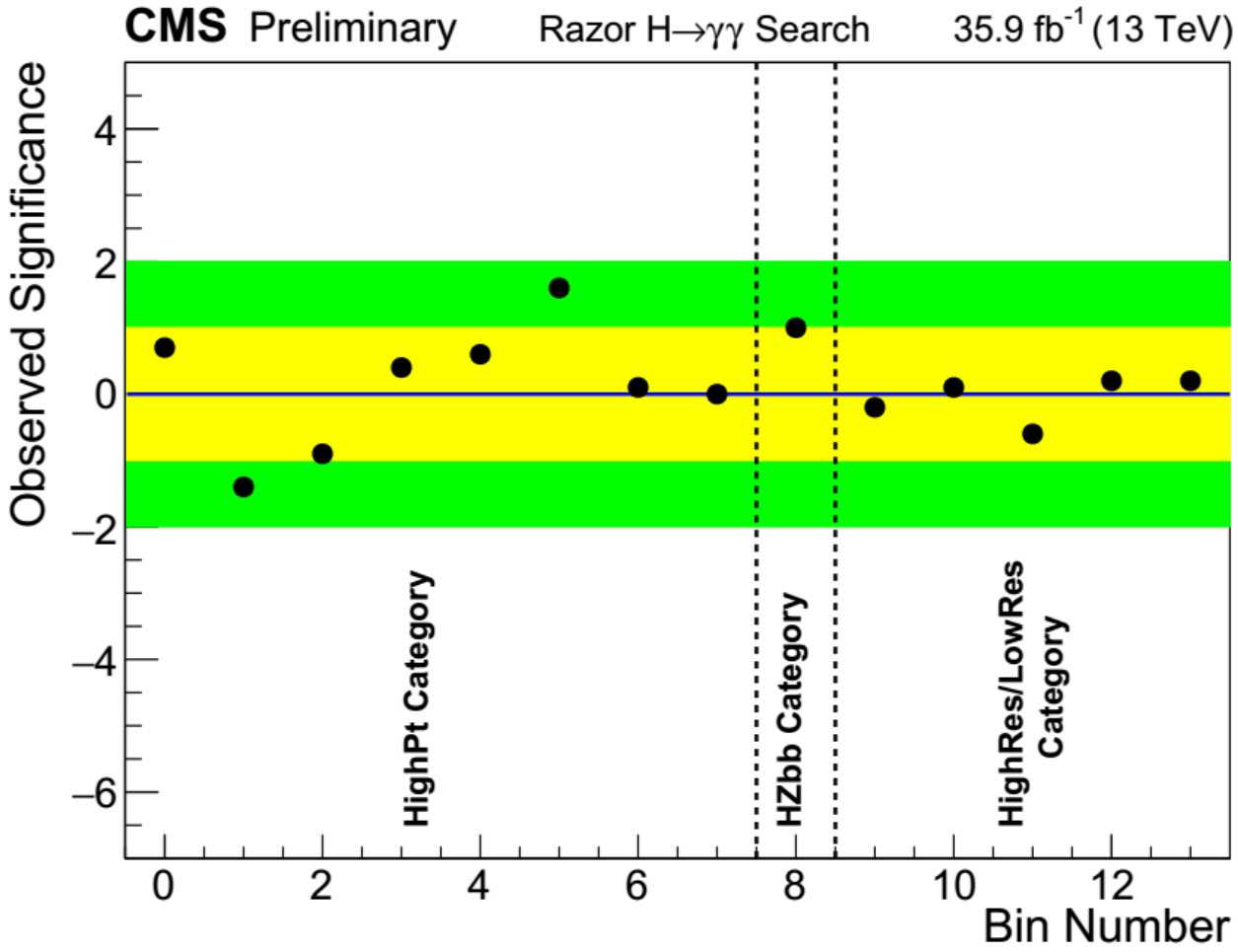


Signal + background fit



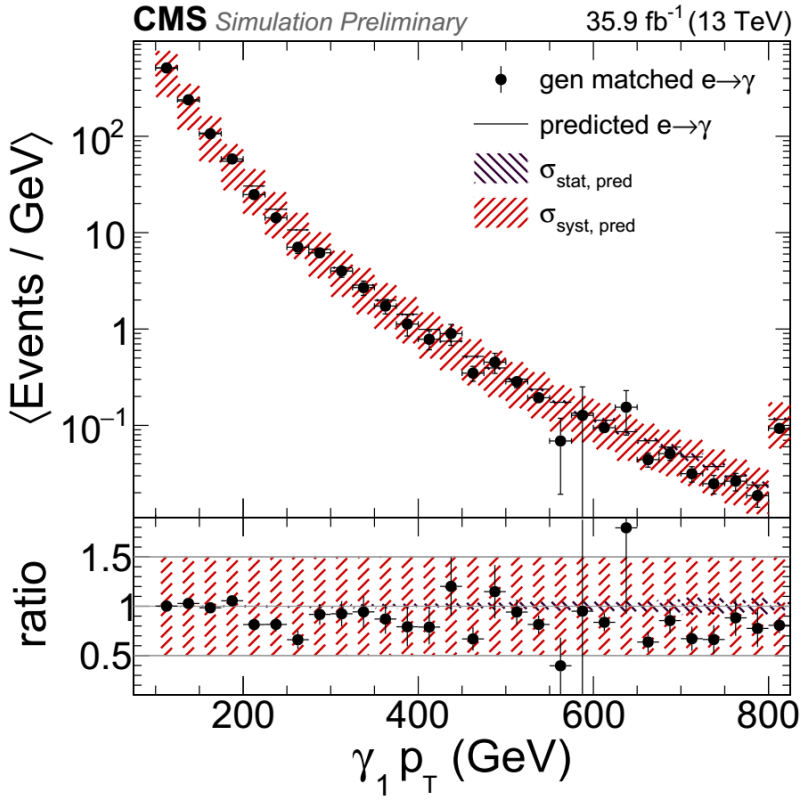
SUS-16-045: Significance of all results

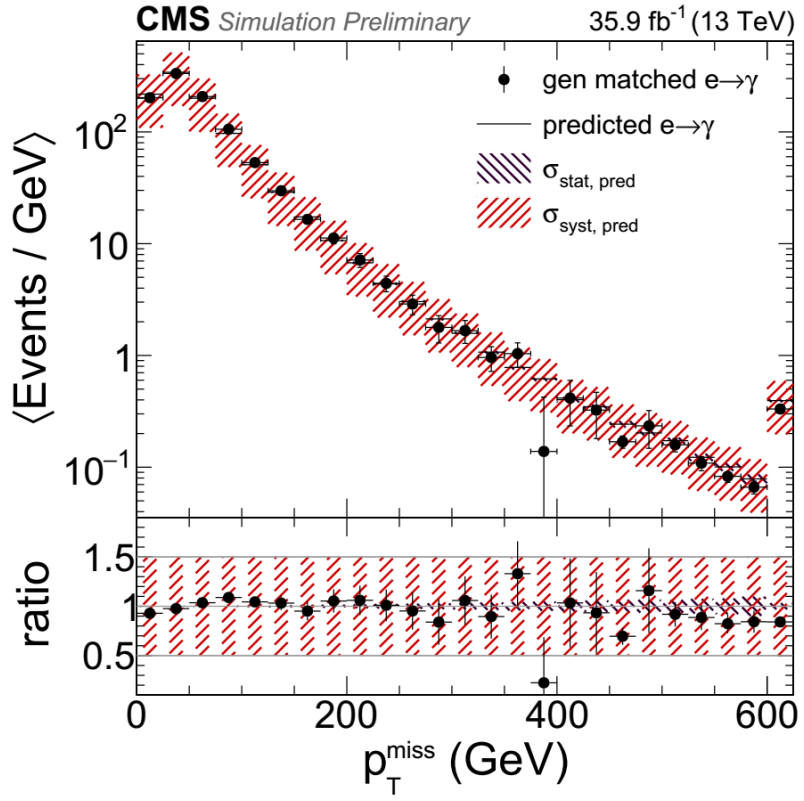
- Most deviations within 1σ



SUS-16-046: Determination of e → γ background

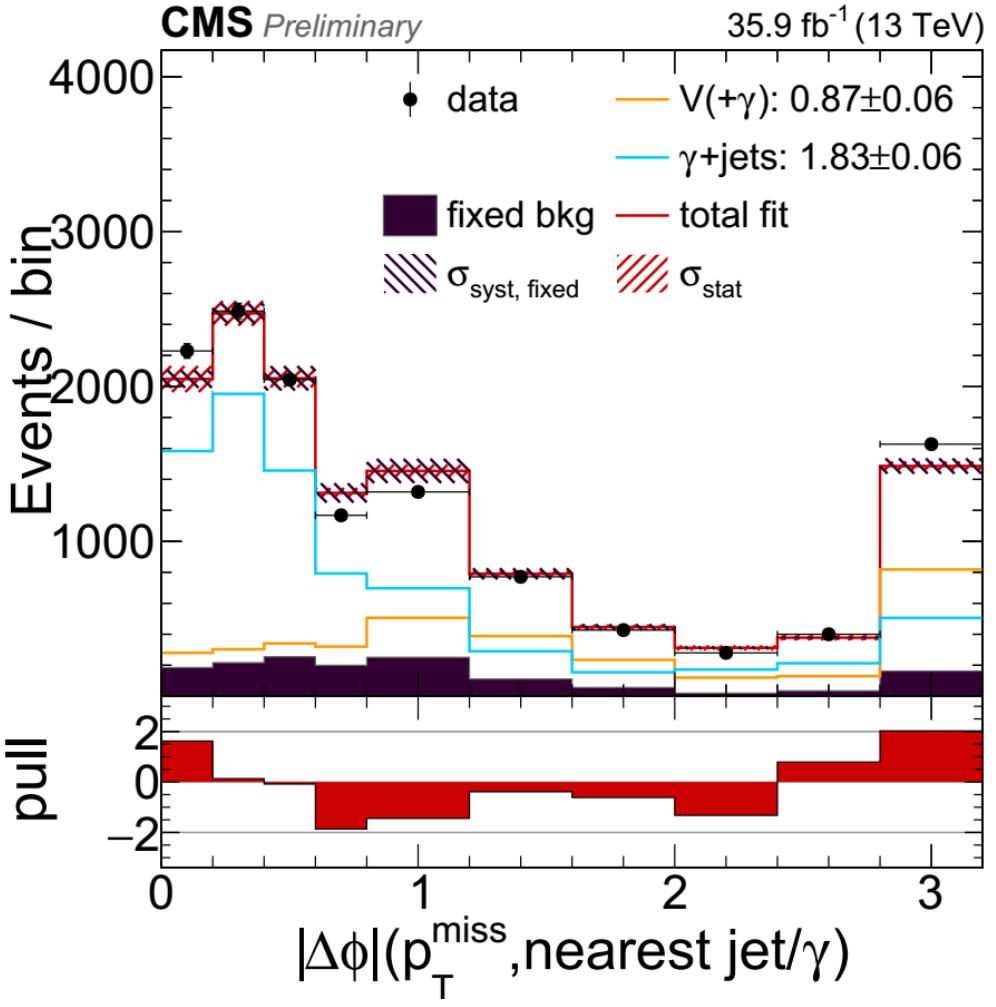
- Data driven estimate of e → γ fake rate
  - Require pixel seed in photon selection
  - Use tag and probe to determine probability e reconstructed as γ
  - Scale distributions by resulting factor $f_{e\to\gamma}$
  - Measured in both simulation and data to obtain systematic uncertainty





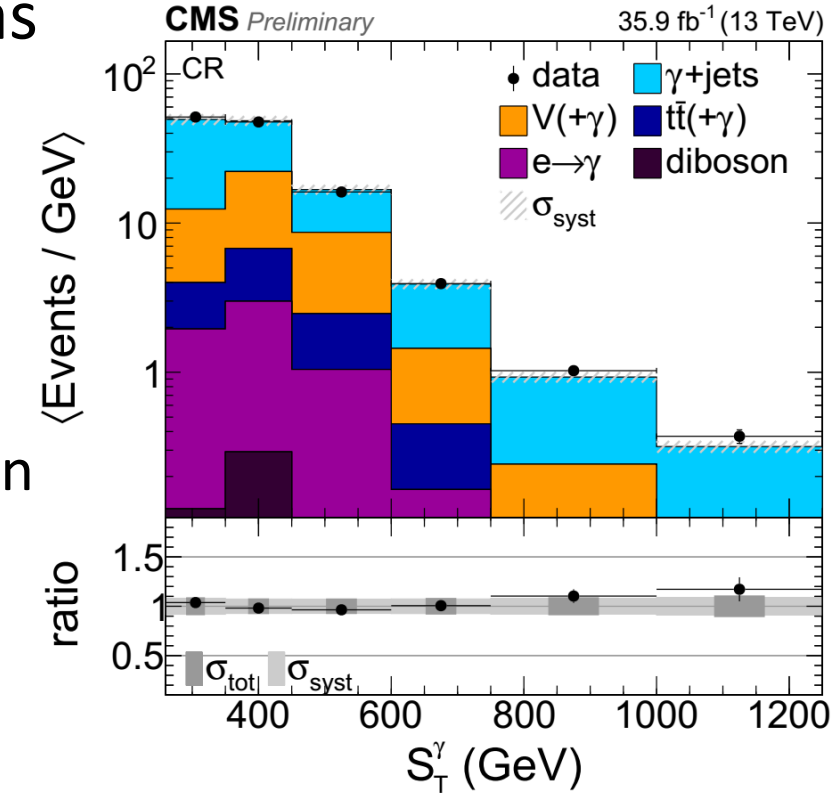
SUS-16-046: Fit of Vγ and γ+jets

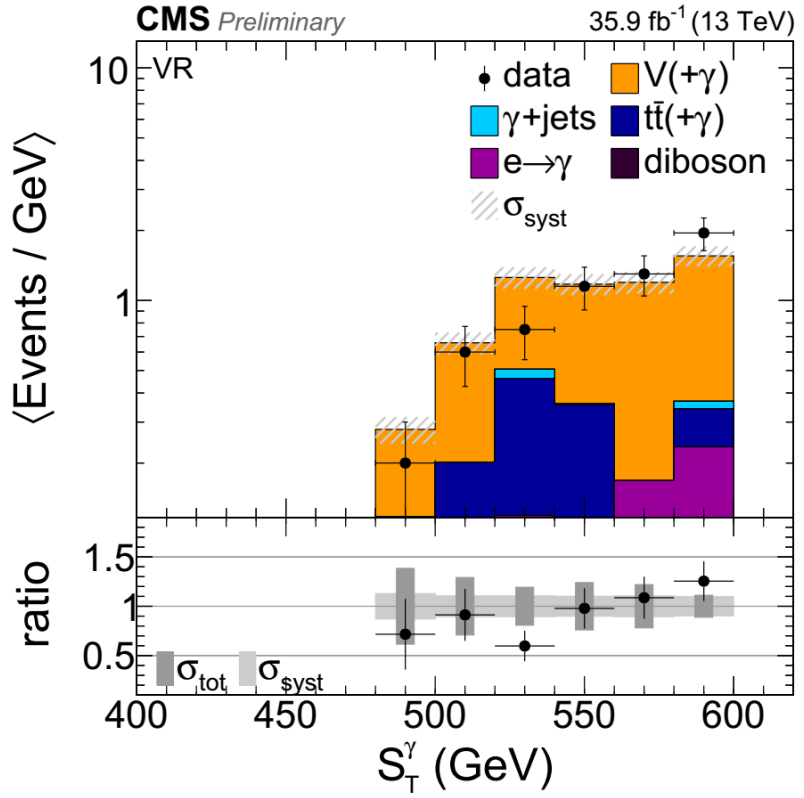
- Simultaneous fit from MC simulation of Vγ (dominant) and γ + jets to data in control region
  - Template fit using $\Delta\varphi\left(p_T^{miss}, \text{nearest jet or } \gamma\right)$
- Subdominant backgrounds fixed



SUS-16-046: Plots in control and VR ($S_T^\gamma < 600$ GeV)

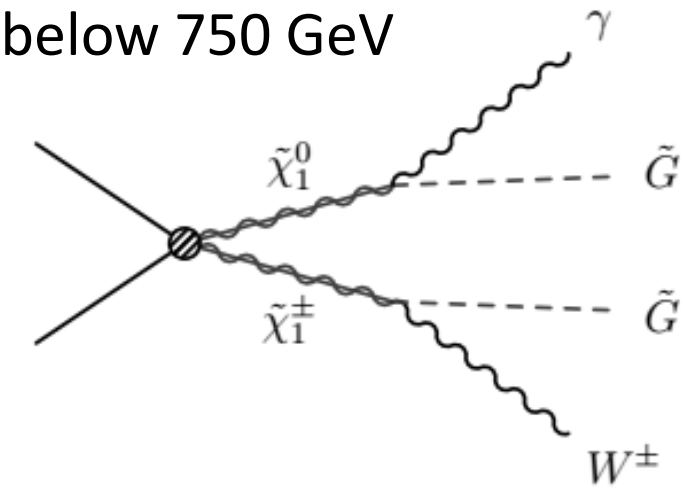
- Control region (CR) has $100 < p_T^{miss} < 300$ GeV and $100 < M_T(\gamma, p_T^{miss}) < 300$ GeV
- Validation region (VR) has same requirements as signal region, but with $S_T^\gamma < 600$ GeV
  - $S_T^\gamma = \sum_i p_T(\gamma_i) + p_T^{miss}$
  - Vγ and γ + jets from simultaneous fit to data in control region
  - Fake rate of e → γ from data via tag and probe

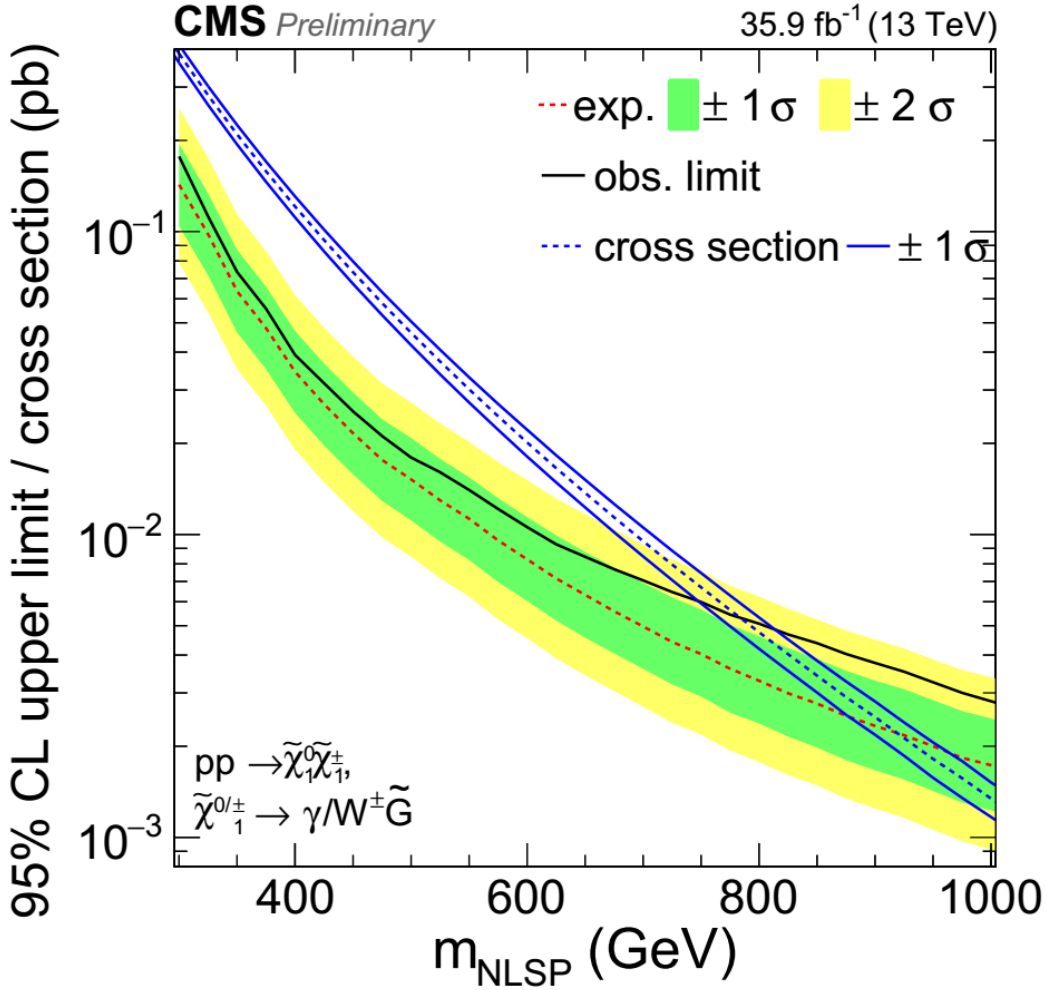




SUS-16-046: Interpretation (electroweak models)

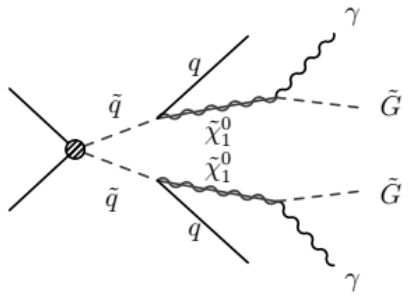
- TChiWg simplified SUSY model
  - Cross section assumes mass-degenerate $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ co-NLSPs
  - Exclude NLSP masses below 750 GeV at 95% CL

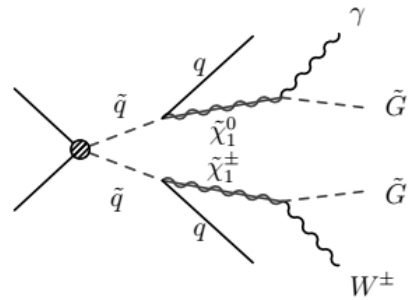


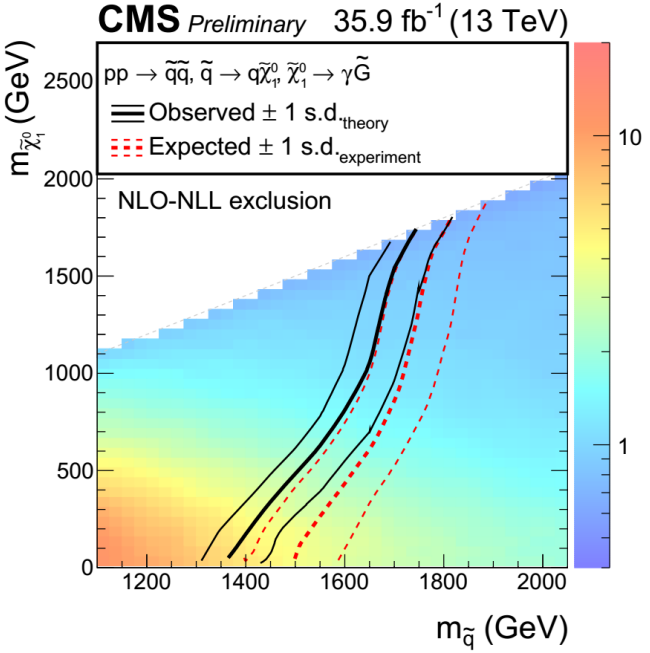


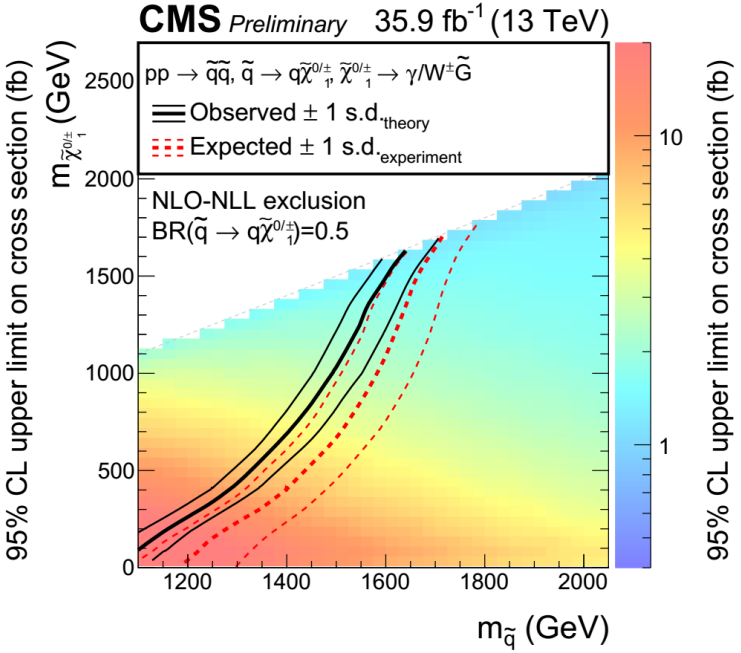
SUS-16-046: Interpretation (strong production models)

- T6gg and T6Wg simplified SUSY models
  - T6Wg cross section assumes mass-degenerate $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ co-NLSPs
  - Can exclude squark masses up to 1750 and 1660 GeV respectively
    - Weaker than gluino limits due to lower production cross section



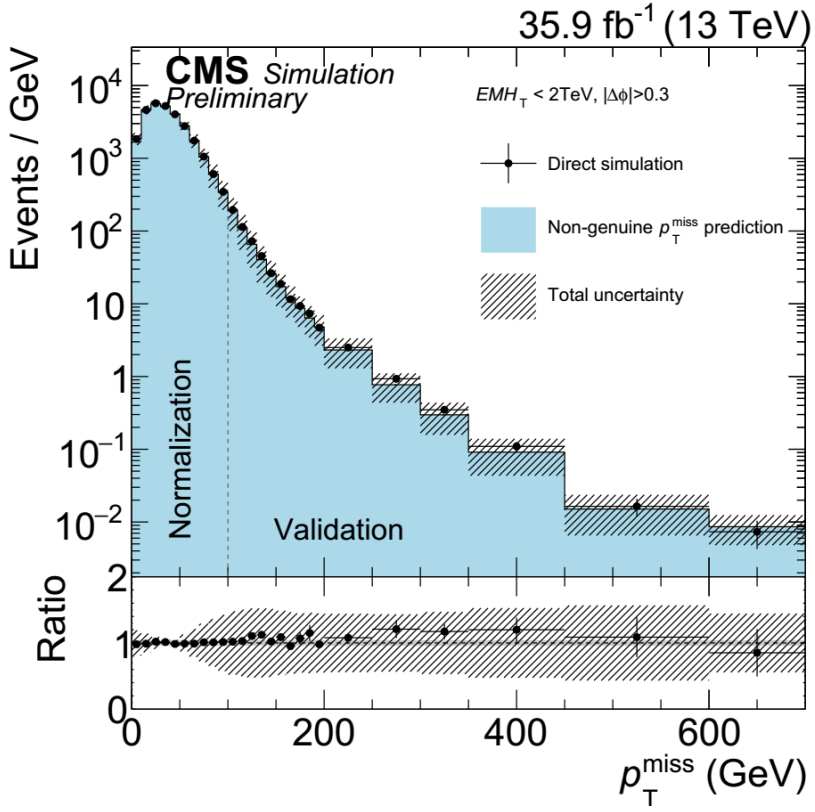


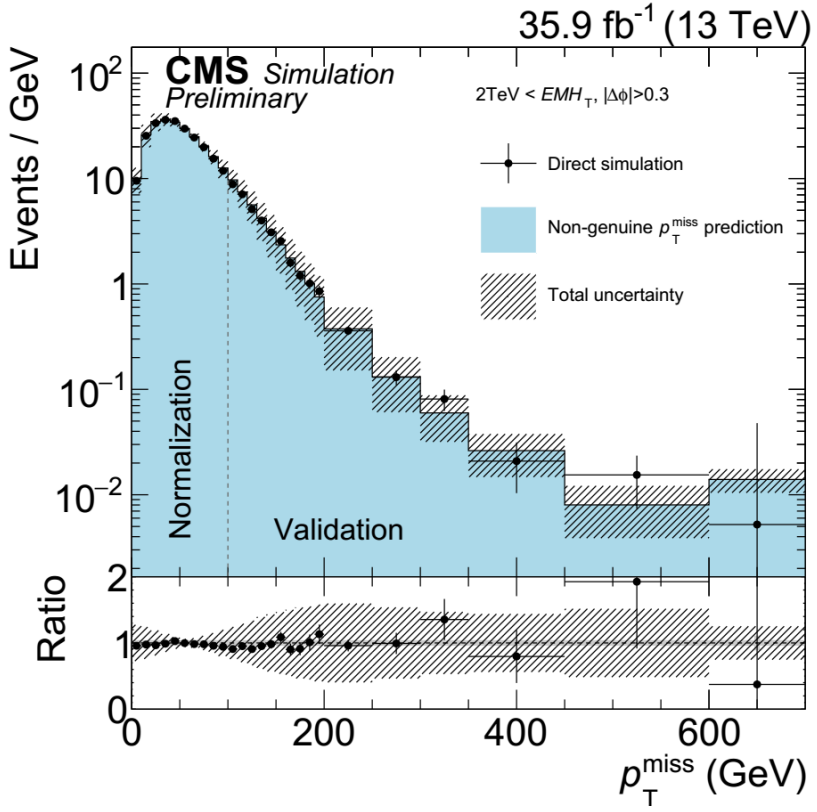




SUS-16-047: Closure tests

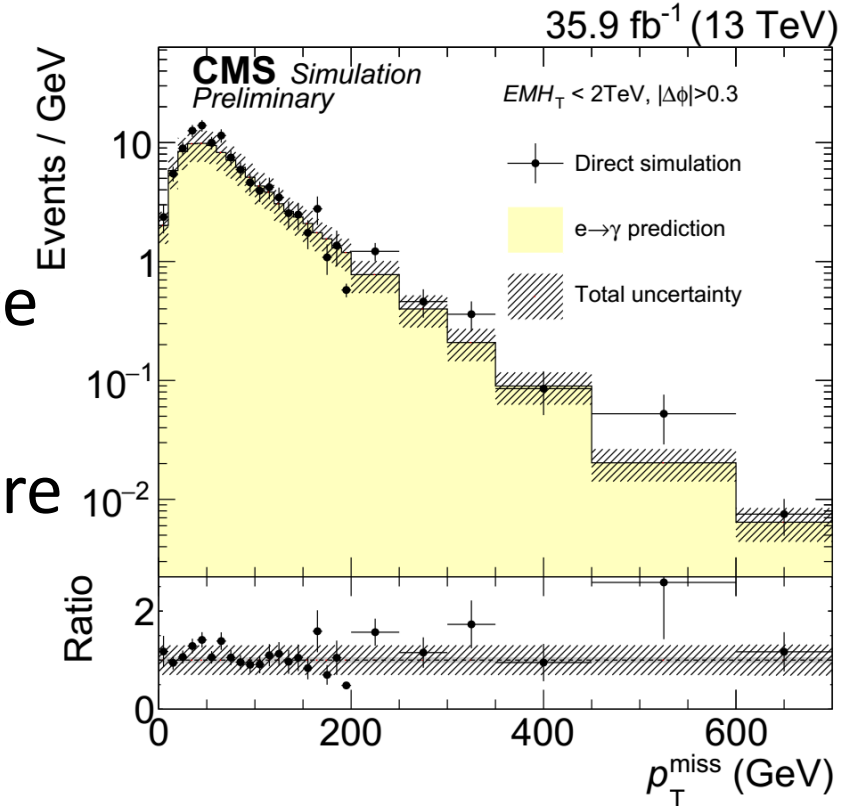
- From γ + jets and H_T-binned QCD simulation
- Points from direct simulation (including non-prompt QCD photons)
- Prediction from shifted jet selection applied to simulation
  - Find very good agreement

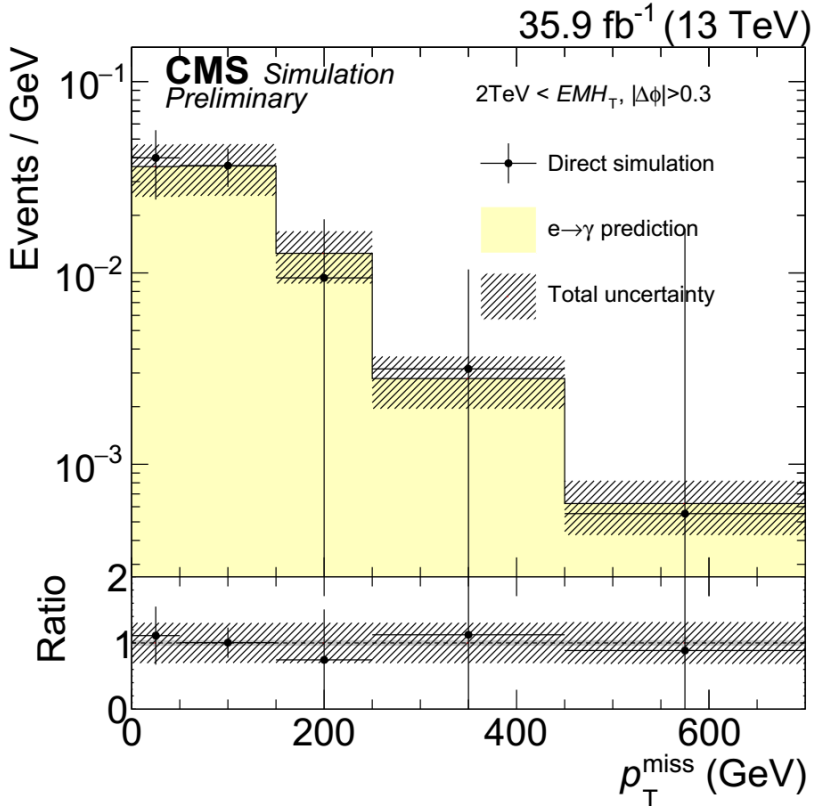




SUS-16-047: e → γ closure on simulation

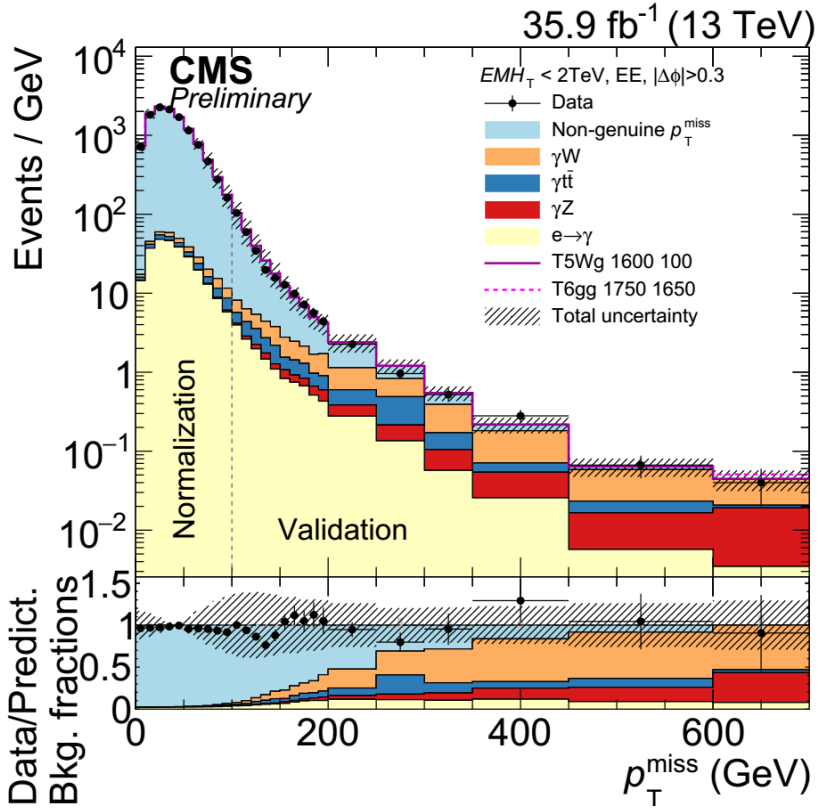
- Similar to previous analysis
- Determine an electron-to-photon misreconstruction probability via tag and probe
- Estimate background by scaling control region with electrons by this rate
- Method applied to simulation to show closure

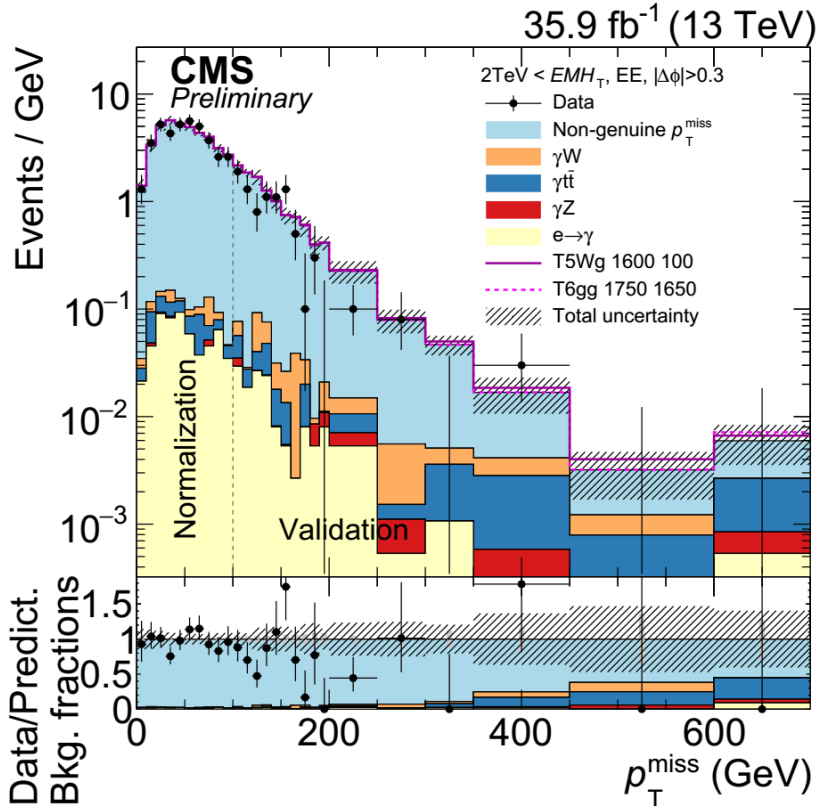




SUS-16-047: Endcap data

- Control region: Require lead photon to be reconstructed in endcap
- Signal stacked with background prediction
  - No signal contamination, as heavy particles decay centrally
- Predictions agree with data within uncertainty





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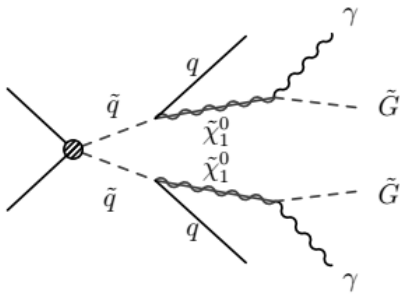

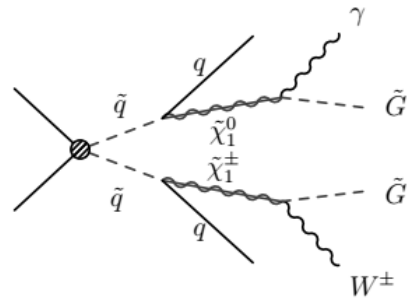

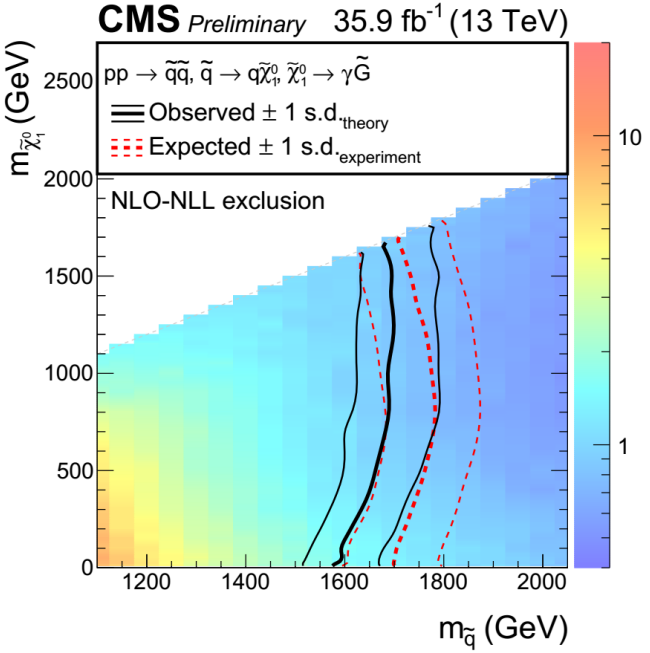

highest