Search for supersymmetry with photons and missing transverse momentum using the CMS detector

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Outline

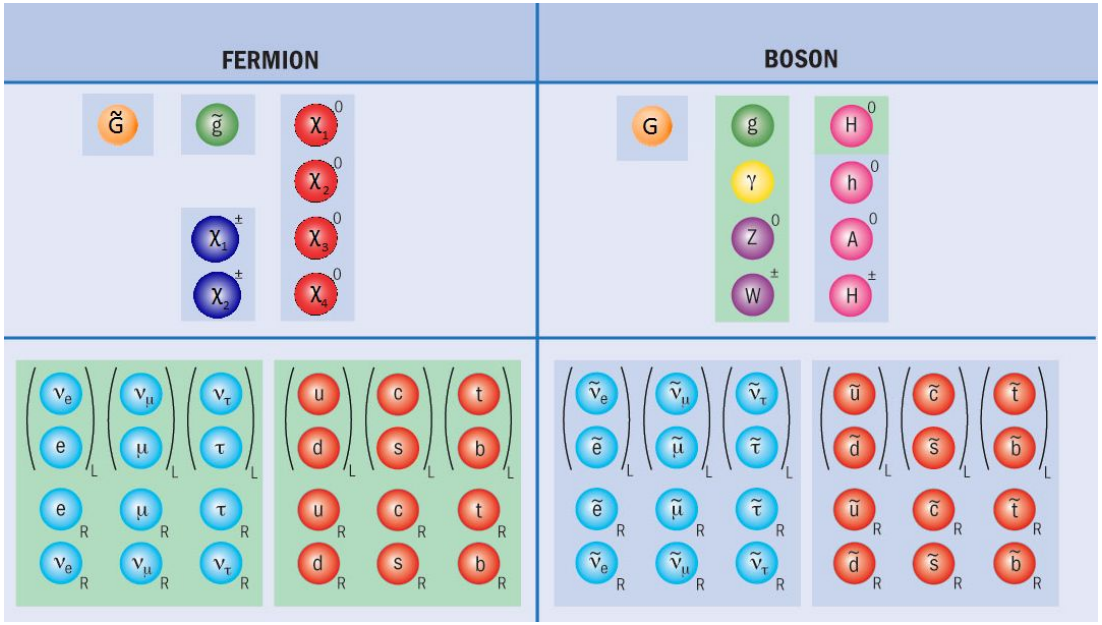
Introduction to SUSY:

- Core idea
- Simplified models [arXiv:1301.2175]
- Experimental aspects

Results from 3 recent analysis + 1 combination:

- SUS-17-011: photon**s** and missing transverse momentum
  strong production: T5gg, T6gg
- SUS-17-012: **a** photon, **a lepton**, and missing transverse momentum
  strong production: T5Wg, T6Wg,
  electroweak production: TChiWg
- CMS-PAS-SUS-18-005: Combined search with photons
- SUS-18-002: **a** photon, **jets**, **b-jets**, and missing transverse momentum
  strong production: T5ggggHG, T5bbbbZG, T5ttttZG, T6ttZG

Introduction and Motivation



What do we mean by SUSY?

- a spacetime symmetry
- relating fermions and bosons
- focus on the Minimal Supersymmetric Standard Model (MSSM)
- Huge parameter space → simplified models

Popular models of spontaneous symmetry breaking:

- Gauge Mediated Supersymmetry Breaking (GMSB) [arXiv:hep-ph/9801271]
- Or General Gauge Mediation (GGM) [arXiv:0801.3278]

R-parity and Lightest SUSY Particle

R-parity conservation assumption

- Baryon number conservation is not hardwired into MSSM
- R-parity is introduced to rule out undesirable couplings:

$$P_R = (-1)^{3(B-L)+2s} = \begin{cases} +1 & \text{for SM particles} \\ -1 & \text{for SUSY partners} \end{cases}$$

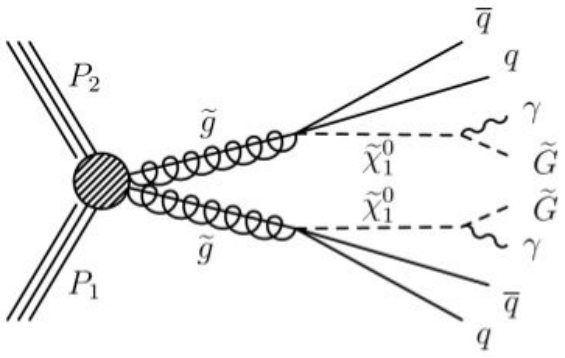
→ SUSY particles are produced in pairs

→ Lightest supersymmetric particles (LSP) are stable

In MSSM with GMSB (GGM) and R-parity conservation:

- **LSP** is always the **gravitino** (WIMP candidate)
- **Next-to-LSP** (NLSP) is typically a **neutralino** (and chargino), can be Bino, Wino, Higgsino like
- The NLSP usually assumed to decay as:

$$\tilde{\chi}_0 \to \tilde{G} + \gamma/Z/H \qquad (\tilde{\chi}^{\pm} \to \tilde{G} + W^{\pm})$$

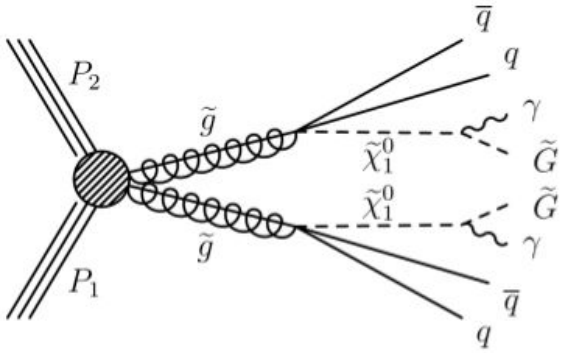


Characterizing SUSY Final States

How to find traces of GMSB MSSM using photons?

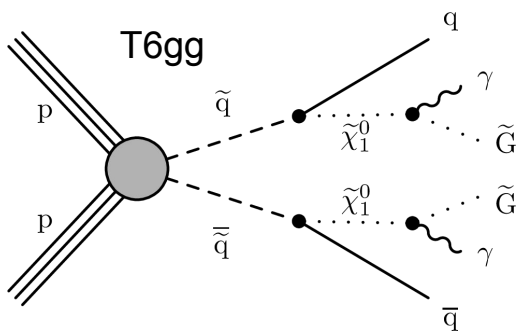
- **Missing Transverse Energy (MET):**
  - Momentum imbalance of all observed physics objects
  - Contributions:
    - MSSM signal: gravitinos
    - SM background: neutrinos, jet momentum mismeasurement
- **Large Hadronic Activity:**
  - Many reconstructed jets
  - $H_T = \sum |p_T^{\text{jet}}(i)|, \quad H_T^\gamma = |p_T^\gamma| + \sum |p_T^{\text{jet}}(i)|$
- **Reconstructed Photon:**
  - Large transverse energy
  - $S_T^\gamma = \sum_i E_T^{\gamma_i} + E_T^{miss}$
  - Invariant mass of MET and photon

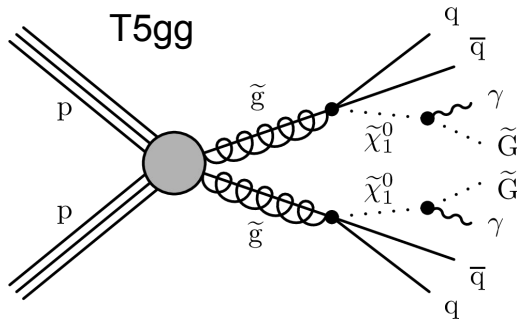
$$M_T^2(\gamma, E_T^{miss}) = 2E_T^{miss} E_T^\gamma [1 - \cos \Delta\phi(\vec{p}_T^{miss}, \gamma)]$$



γ + MET in strong production SUS-17-011

- Framework: GMSB
- Process:
  - Gluino pair production (T5gg)
  - Squark pair production (T6gg)
- Data used: 35.9 fb^{-1}

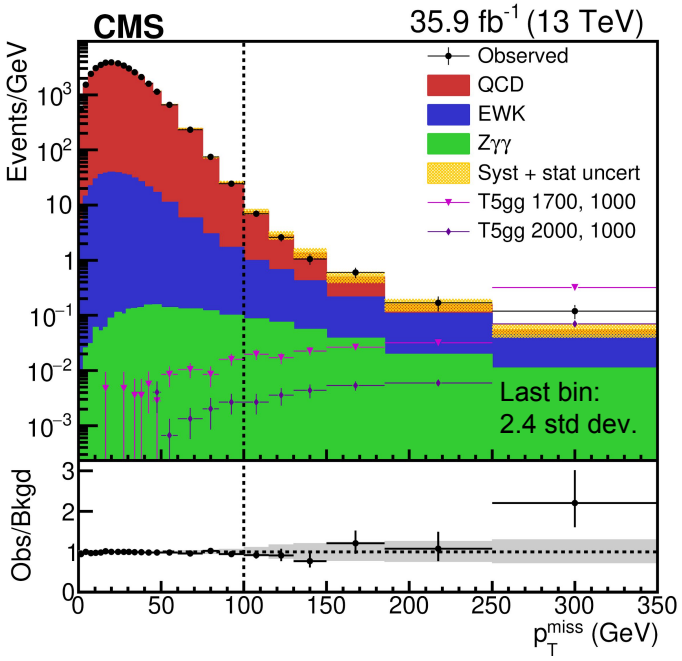




Event Selection:

- **Diphoton trigger**
  - p^{γ}_T>30 (18) GeV, $m_{\gamma\gamma}$>95 GeV
- **Two photons**
  - p^{γ}_T>40 GeV for both
  - $m_{\gamma\gamma}$>105 GeV
- **p^{miss}_T>100 GeV**
- **Light lepton veto**:
  - Muon: p_T>25 GeV, |η|<2.4
  - Electron: p_T>25 GeV, |η|<2.5

→ 6 signal search **bins according to p^{miss}_T**



Backgrounds:

QCD multijet

- **Data driven**
- **ABCD like**

EWK

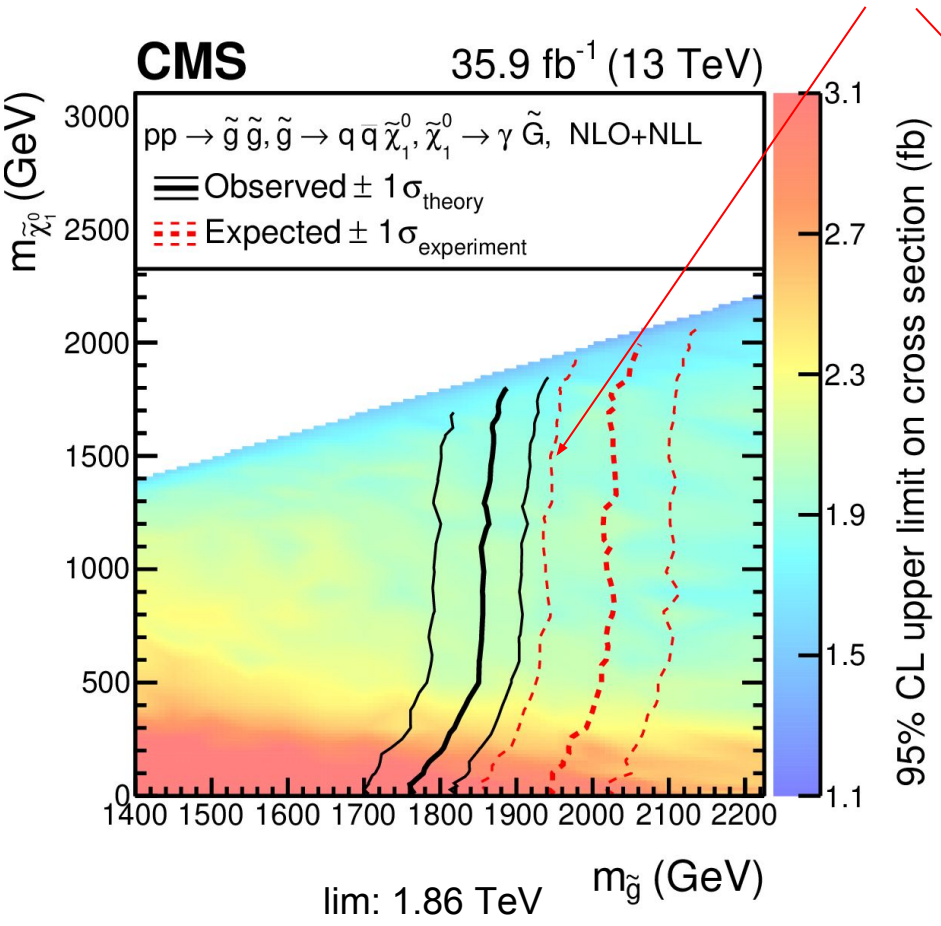
- **Data driven**
- **From e→ γ misidentification rate**

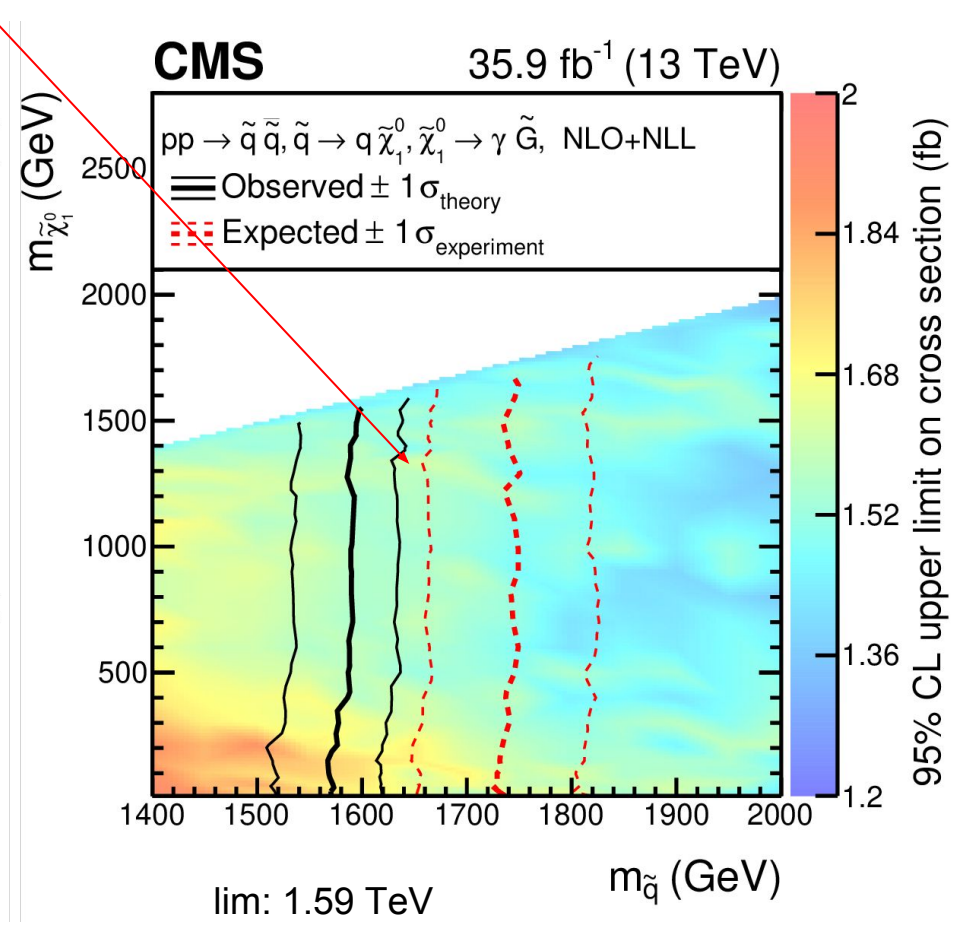
Z→ $\nu\nu$

- **NLO simulation**

γ + MET in strong production SUS-17-011

Effect of last bin upward fluctuation

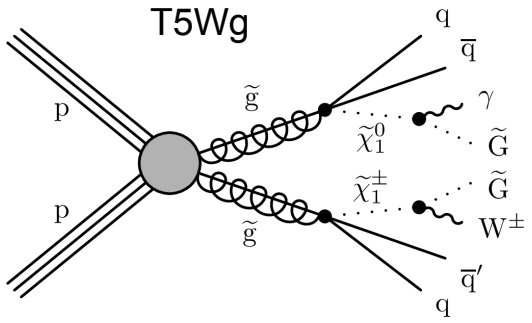


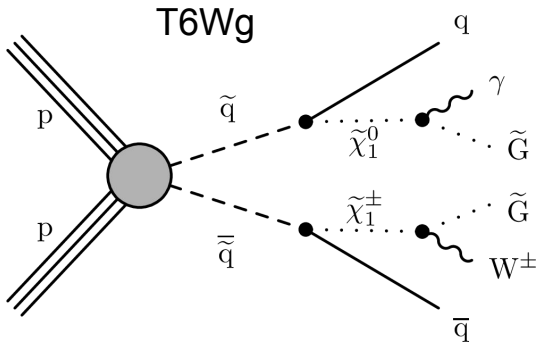


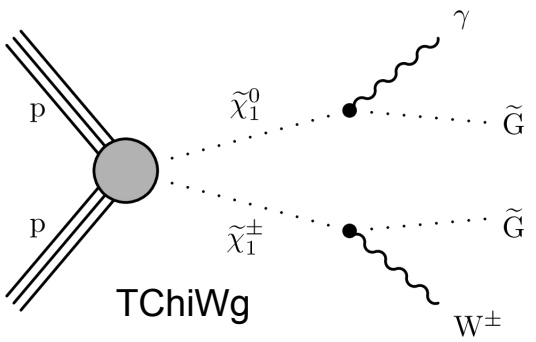
Over 200 GeV improvement for the observed exclusion for both models

γ + MET + lepton SUS-17-012

- Framework: GGM
- Process:
  - Gluino pair production
  - Squark pair production
  - EWK production
- Data used: 35.9 fb^{-1}







Event Selection: two channels:

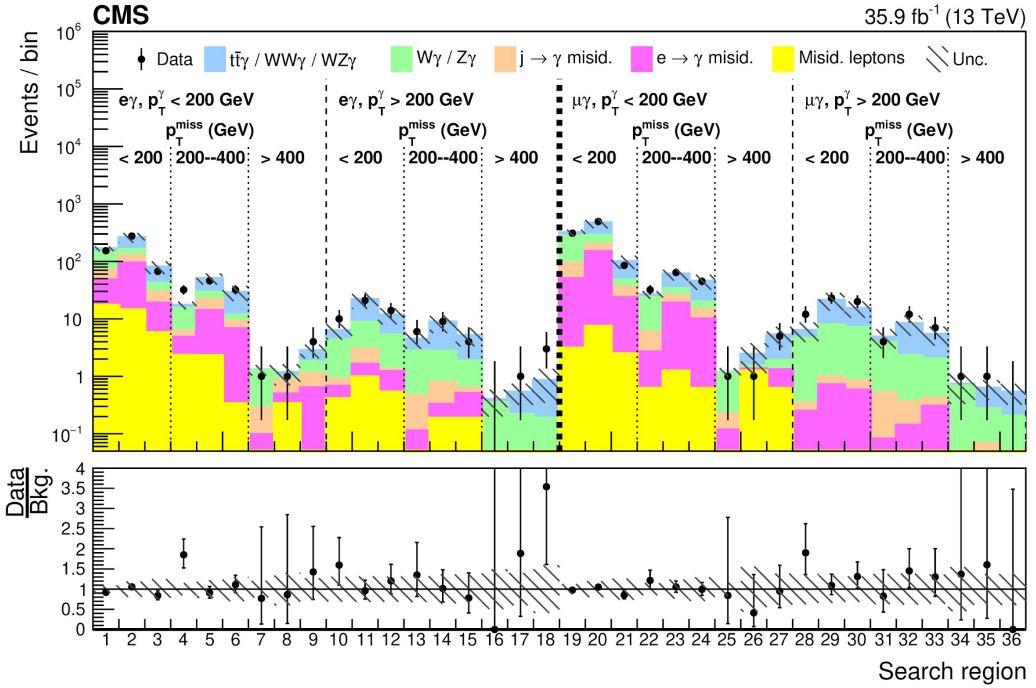
	$e\gamma$	$\mu\gamma$
Trigger:	**diphoton trigger** p^γ_T>30 (18) GeV, $m_{\gamma\gamma}$>95 GeV	**two $\mu\gamma$ triggers** iso γ, p^γ_T>30 GeV, p^μ_T>17 GeV p^γ_T>38 GeV, p^μ_T>38 GeV
Photon:	isolated photon, **p^γ_T>35 GeV**, $\lvert\eta\rvert$<1.44, **$\Delta\Phi(\ell,\gamma)$>0.3** Distance between leading p_T photon and lepton **ΔR>0.8**	
Lepton:	**p^ℓ_T>25 GeV** 1.44<$\lvert\eta\rvert$<1.56 rejected **$m_{e\gamma}$>100 GeV (Z veto)**	
MET:	**p^{miss}_T>120 GeV, M_T > 100 GeV (W veto)**	

→ Signal region is binned in:
p^γ_T, p^{miss}_T, H_T
→ **2x18 bins**

γ + MET + lepton SUS-17-012

Background estimation:

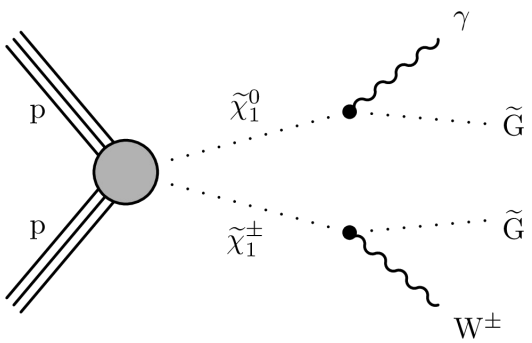
- Misidentified photons (no genuine prompt photon)
  - Electron → Photon (data driven, rate from Z tag-and-probe)
  - Jet → Photon (semi data driven)
- EWK & misidentified leptons (lepton not from prompt W/Z decay or not lepton)
  - EWK: Wγ, Zγ (shape from simulation)
  - Rare EWK: diboson+γ or ttγ (simulation)
  - Misidentified leptons: hadron decay, photon conv, misidentified jets (shape from non-iso ℓ CR)

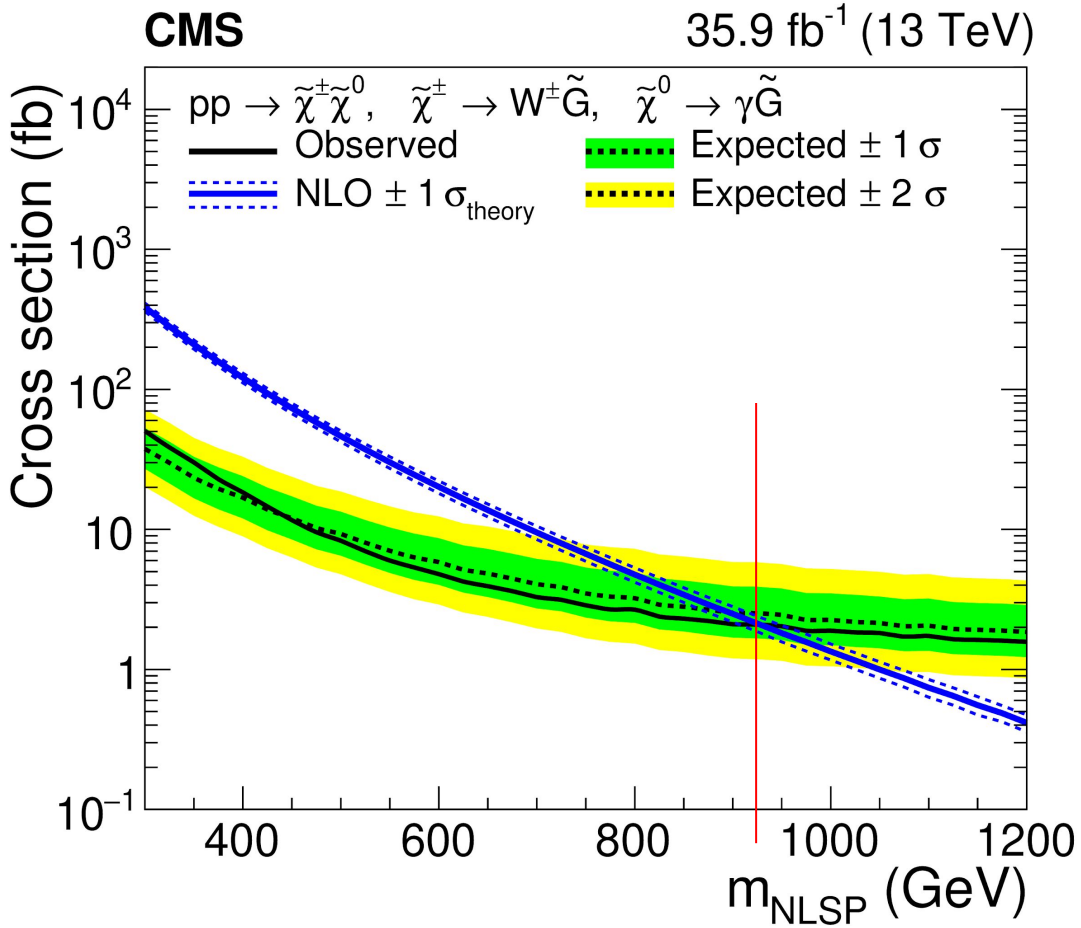


γ + MET + lepton SUS-17-012

EWK Channel Results:

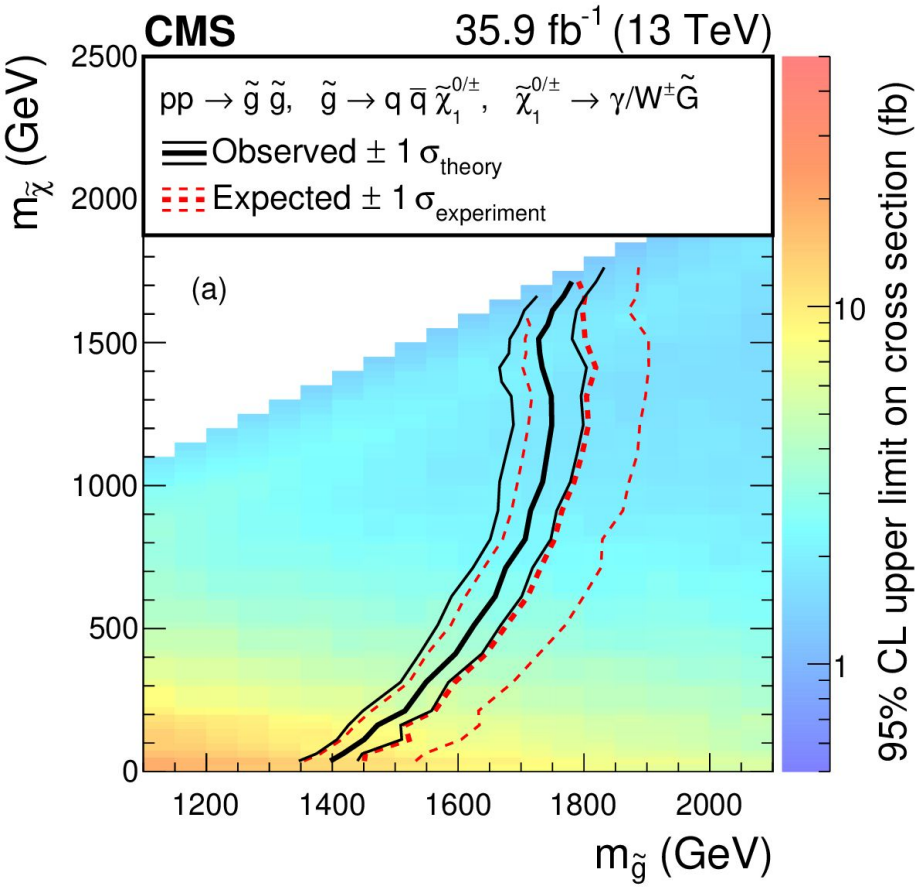
- Limit on NLSP mass in the TChiWg model
- 930 GeV (150 GeV improvement)
- Expected and observed exclusions are in good agreement

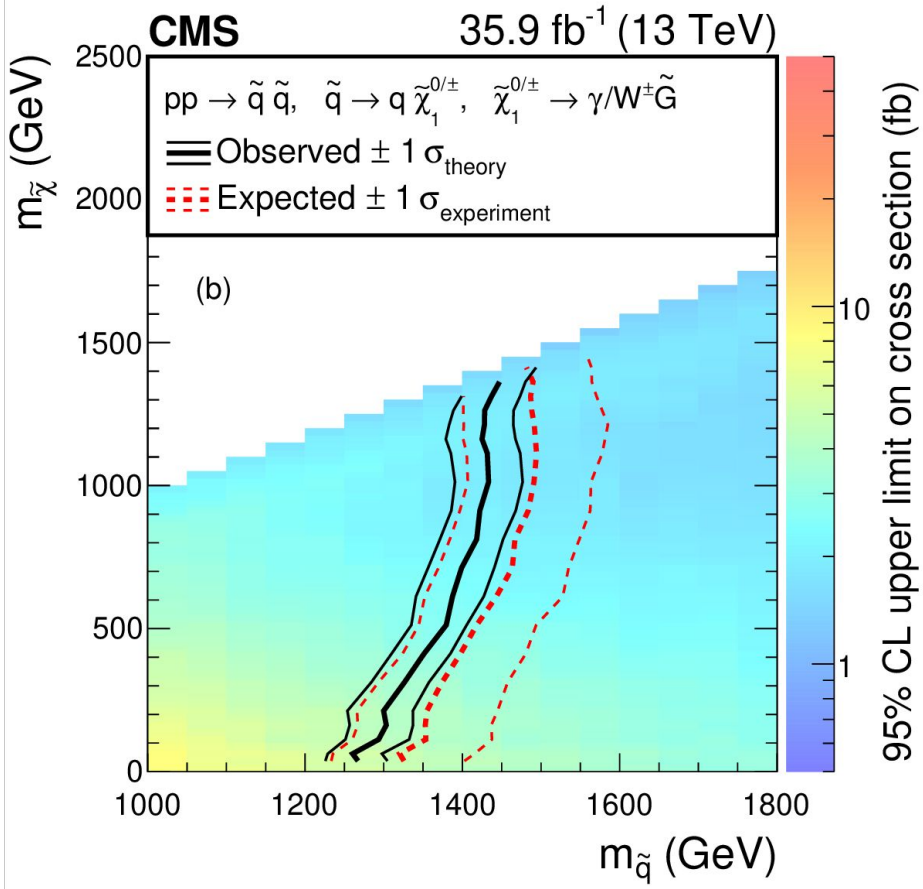




γ + MET + lepton SUS-17-012

Strong Channel Results:

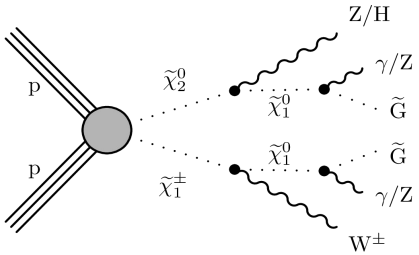


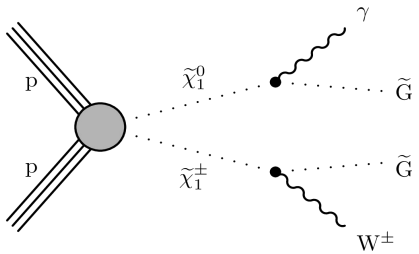


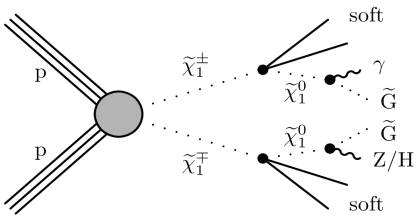
Up to 1.75 (1.43) TeV

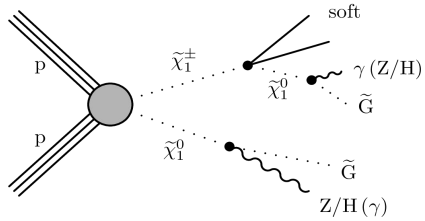
GGM Combination CMS-PAS-SUS-18-005

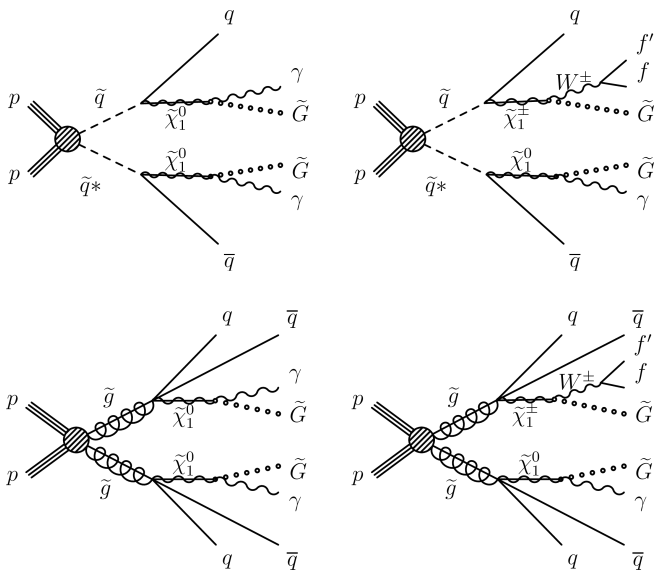
- Framework: GGM
- Data used: 35.9 fb^{-1}
- **Four analyses combined**:
  - #1 and #2 in this talk
  - Other 2 were presented at DIS2018:
    - SUS-16-046: electroweak SUSY productions with photons + MET
    - SUS-16-047: strong SUSY productions with photons + MET + large transverse hadronic activity
  - Overlaps removed in an optimized way using additional vetoes

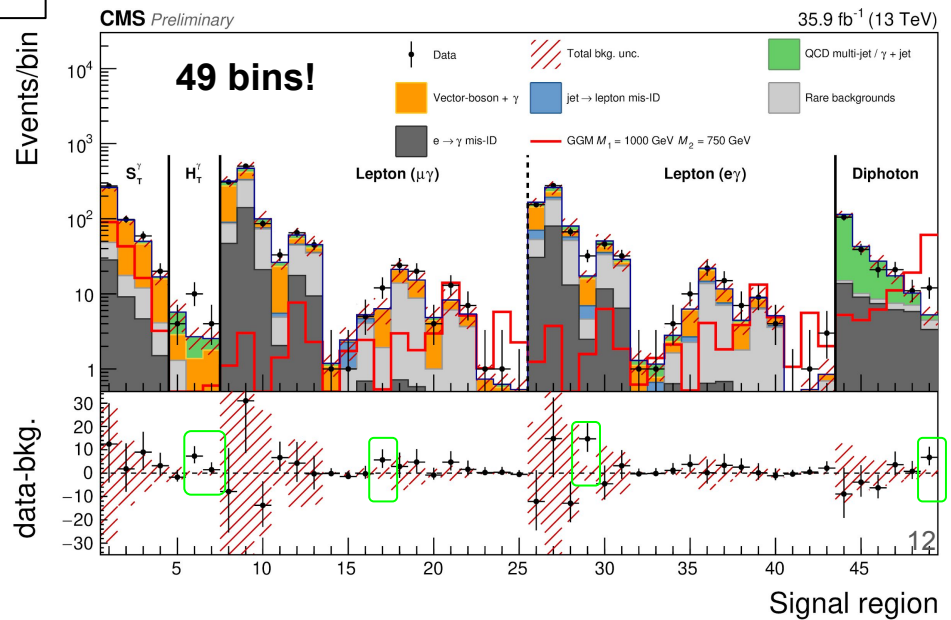




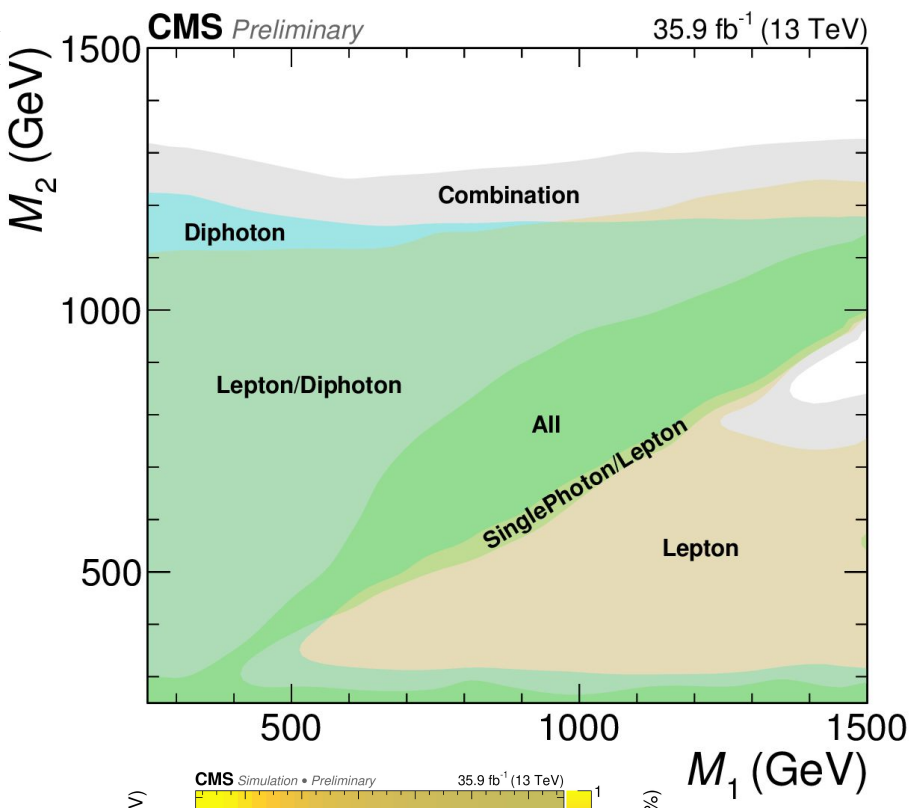


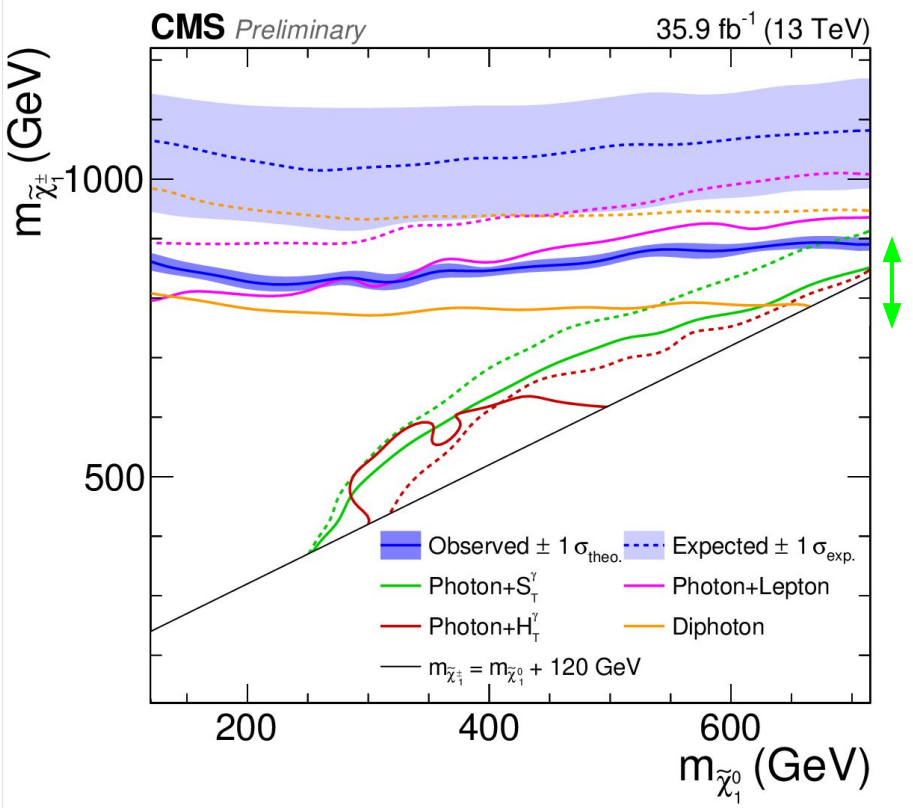


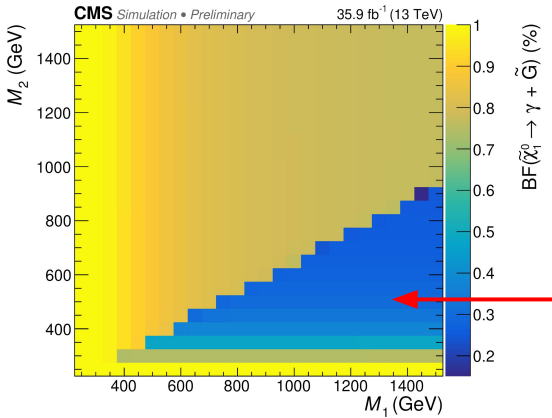




GGM Combination CMS-PAS-SUS-18-005

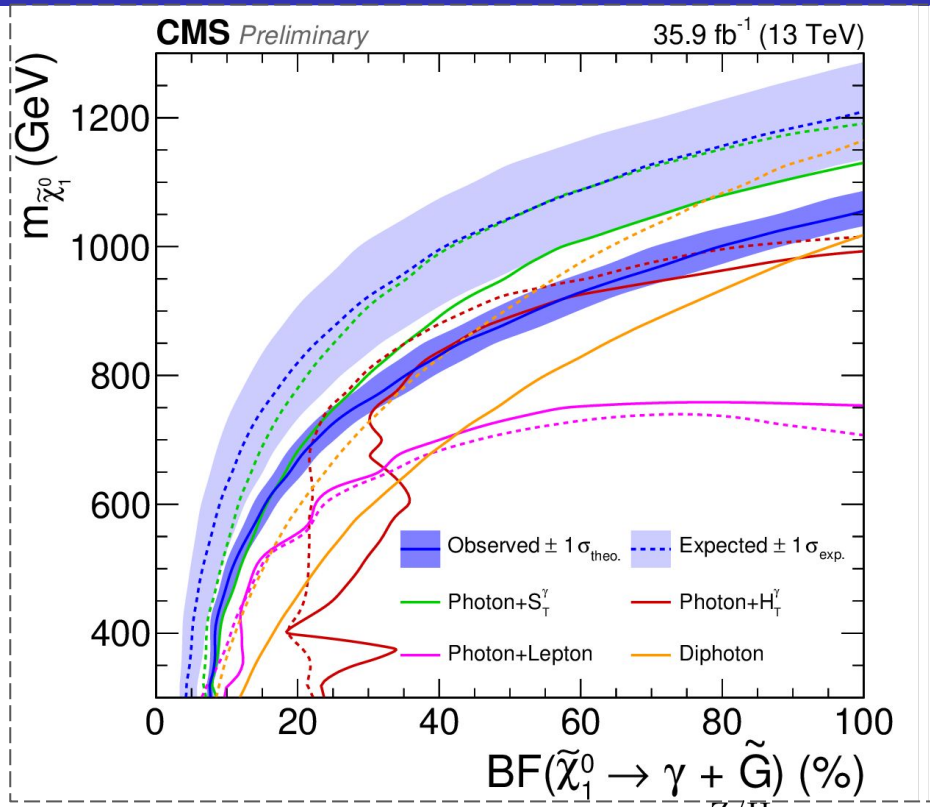


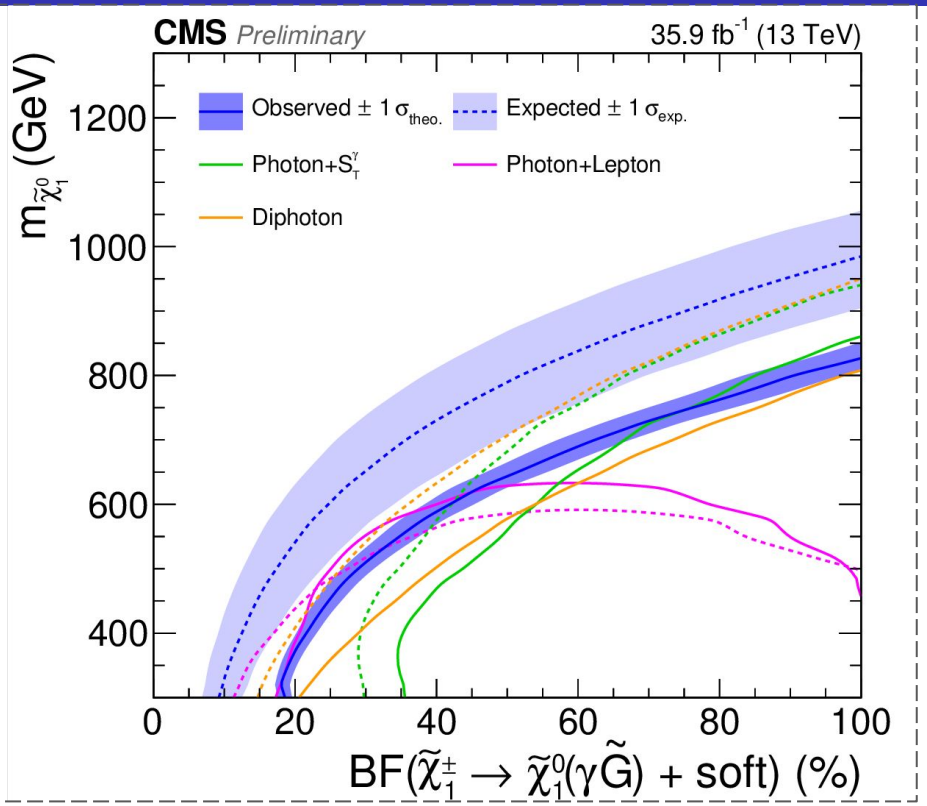


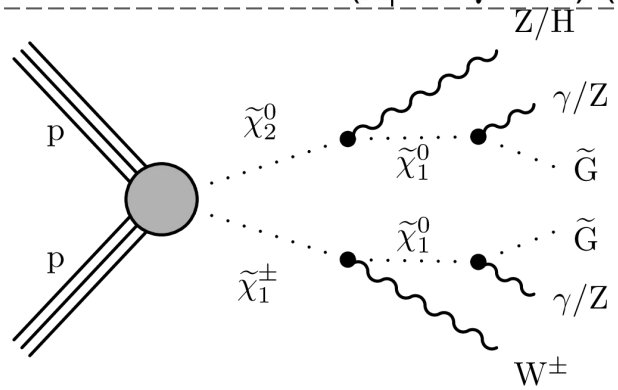


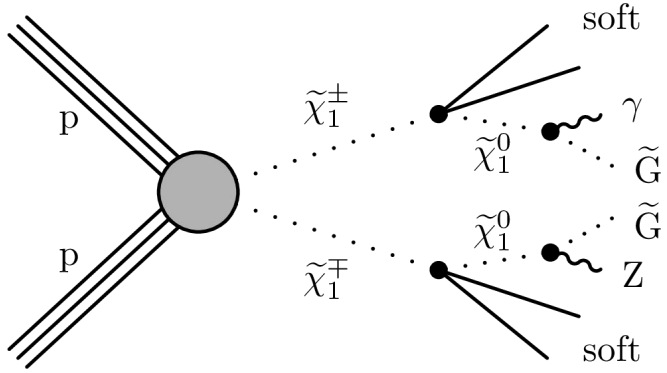
Wino like NLSP

GGM Combination CMS-PAS-SUS-18-005

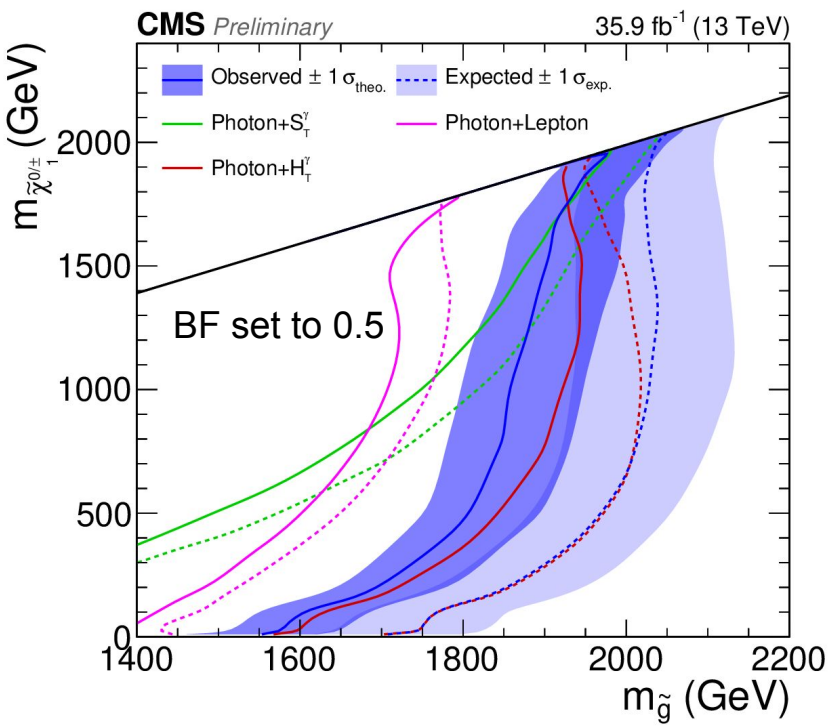


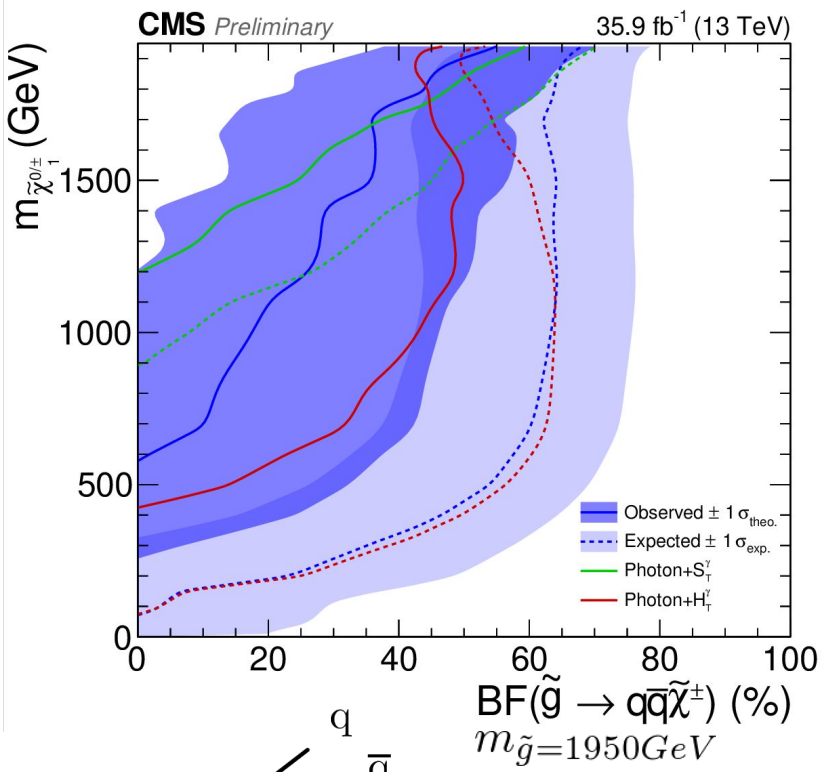




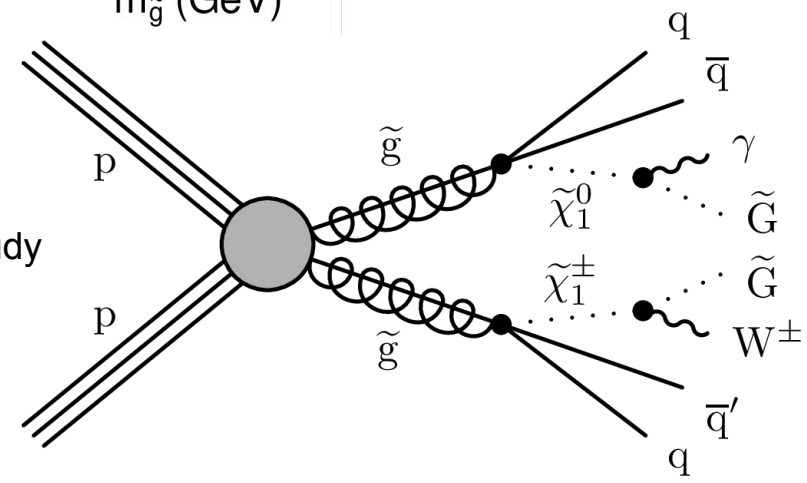


GGM Combination CMS-PAS-SUS-18-005





Diphoton is not used.
→ no diphoton veto in large H_T study



γ + MET + (b-)jets in strong production

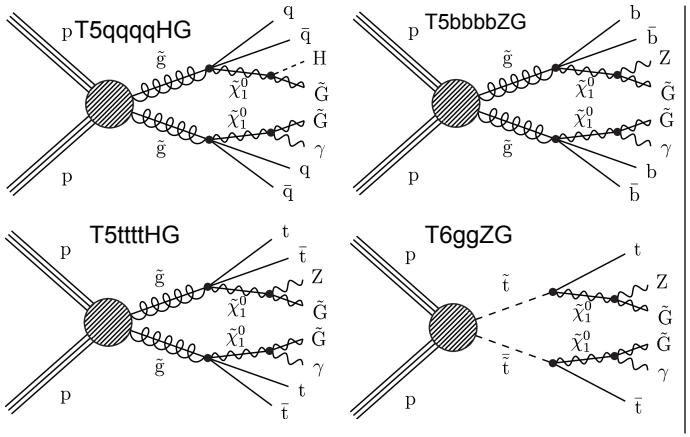
SUS-18-003

- Framework: GMSB
- Process:
  - Gluino pair production
  - Stop pair production
- Data used: 35.9 fb^{-1}

Event Selection:

- **Photon trigger**
  - p^{γ}_T>90 GeV if H^{γ}_T>600 GeV
  - p^{γ}_T>165 GeV otherwise
- Photon:
  - **p^{γ}_T>100 GeV & H^{γ}_T>800 GeV**
  - Or **p^{γ}_T>190 GeV & H^{γ}_T>500 GeV**
- MET:
  - **p^{miss}_T>100 GeV**
- Jets:
  - **N_{jets}>2 and $\Delta\phi_{jet,MET}$>0.3**
- **Vetos**:
  - Electrons
  - Muons
  - Charged hadron tracks

→ **25 search bins in N_{jets}, $N_{b\text{-}jets}$, p^{miss}_T**



Backgrounds:

Lost ℓ or hadronic τ decay

- 1ℓ CR, TF ← MC
- τ from BF

W → eν and e → γ

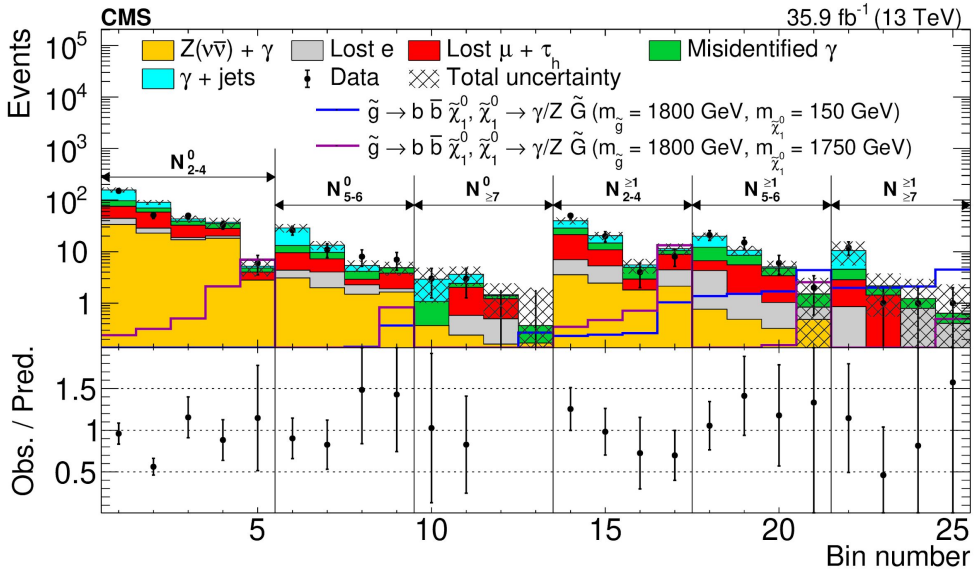
- 1e, 0 γ CR, TF ← MC

Zγ → $\nu\nu\gamma$

- Shape from MC
- Normalization: Z($\ell^+\ell^-$)

QCD multijet

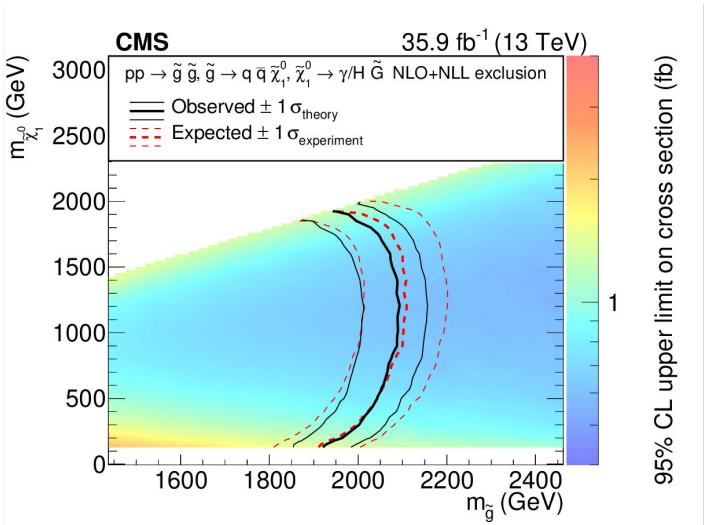
- $\Delta\phi_{jet,MET}$< 0.3 CR
- MET shape from MC

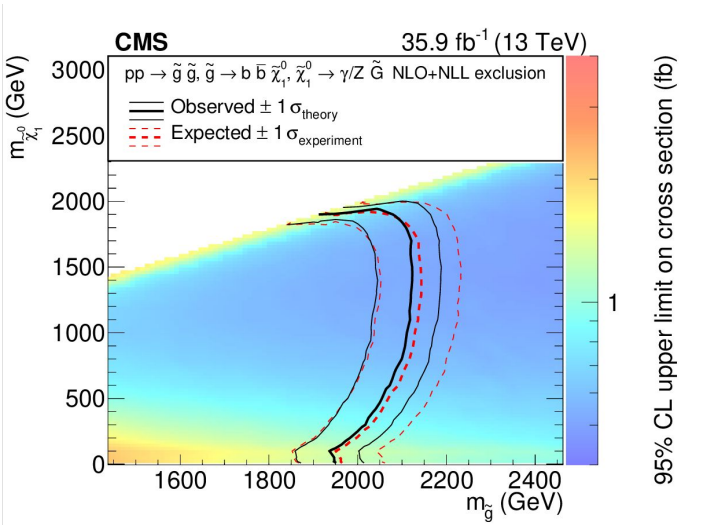


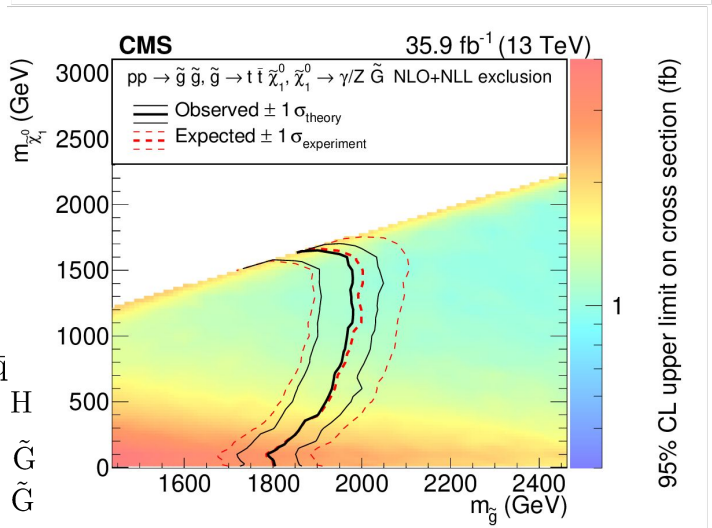
γ + MET + (b-)jets in strong production

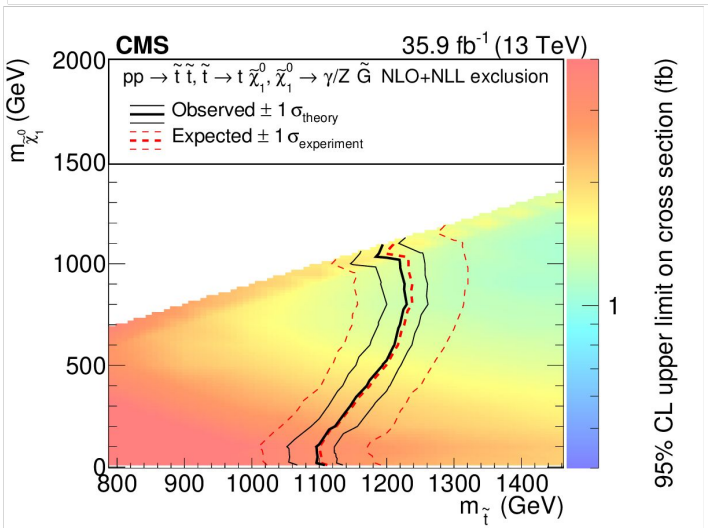
SUS-18-003

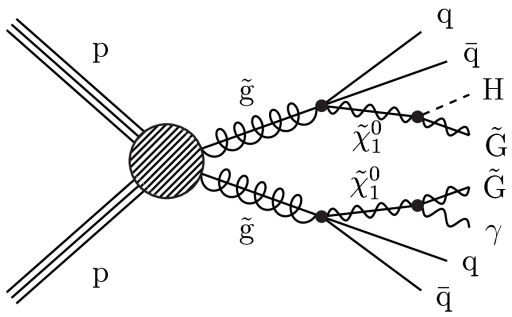
- Good agreement between expected and observed exclusion
- Limits tend to $m_{\tilde{\chi}0}$ degrade at extreme as expected due to less jets or less MET in these regions





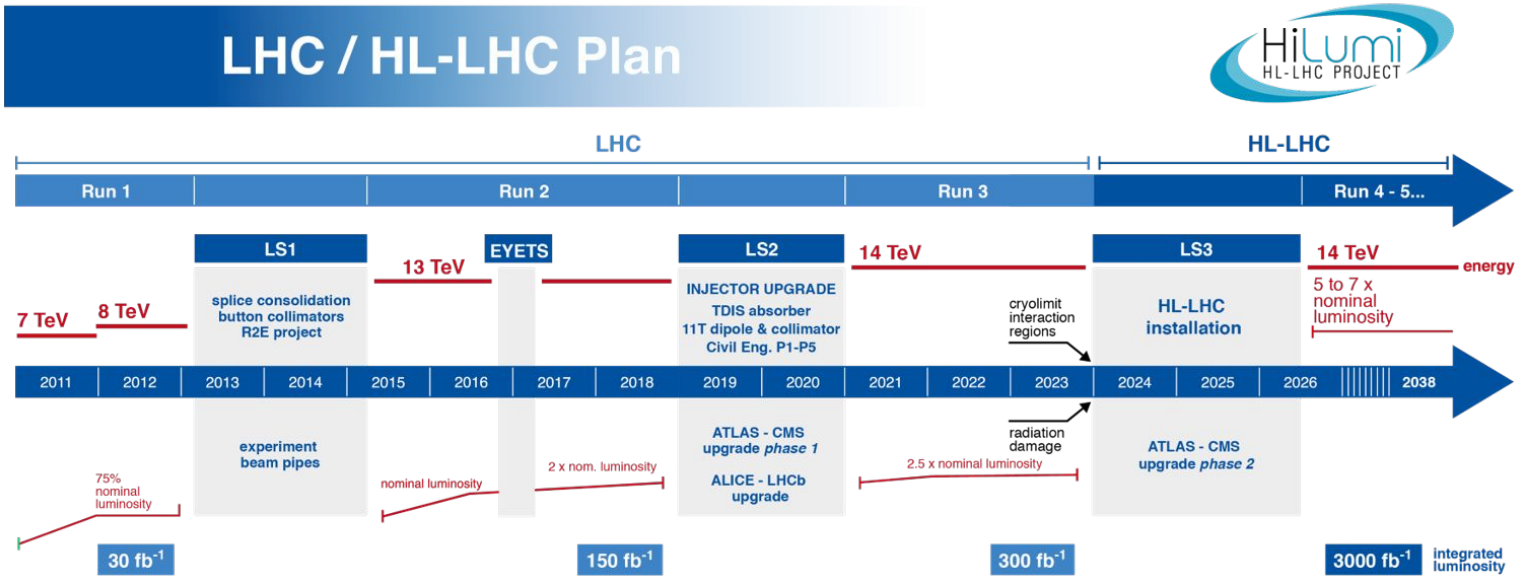






Summary

- Searches address a large area of the GMSB (GGM) MSSM parameter space
- Results consistent with SM, they provide limits on SUSY models, particle masses
- Efforts are made to combine the different results
- No signs of SUSY yet but it could still be hiding at many places
- Only ~5% of the full pp integrated luminosity recorded yet

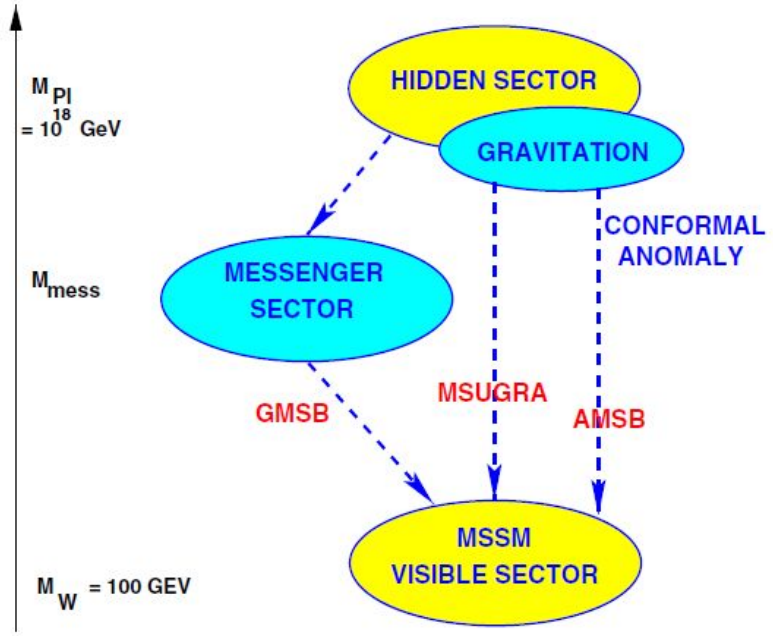


BACKUP

SUSY Breaking

Why do we see no traces of SUSY at low energy?

- *Sleptons should be easy to see unless **SUSY is broken***!
- Several symmetry breaking mechanisms proposed
  - Eg: Gauge Mediated Supersymmetry Breaking (GMSB) [arXiv:hep-ph/9801271]
  - Or General Gauge Mediation (GGM) [arXiv:0801.3278]



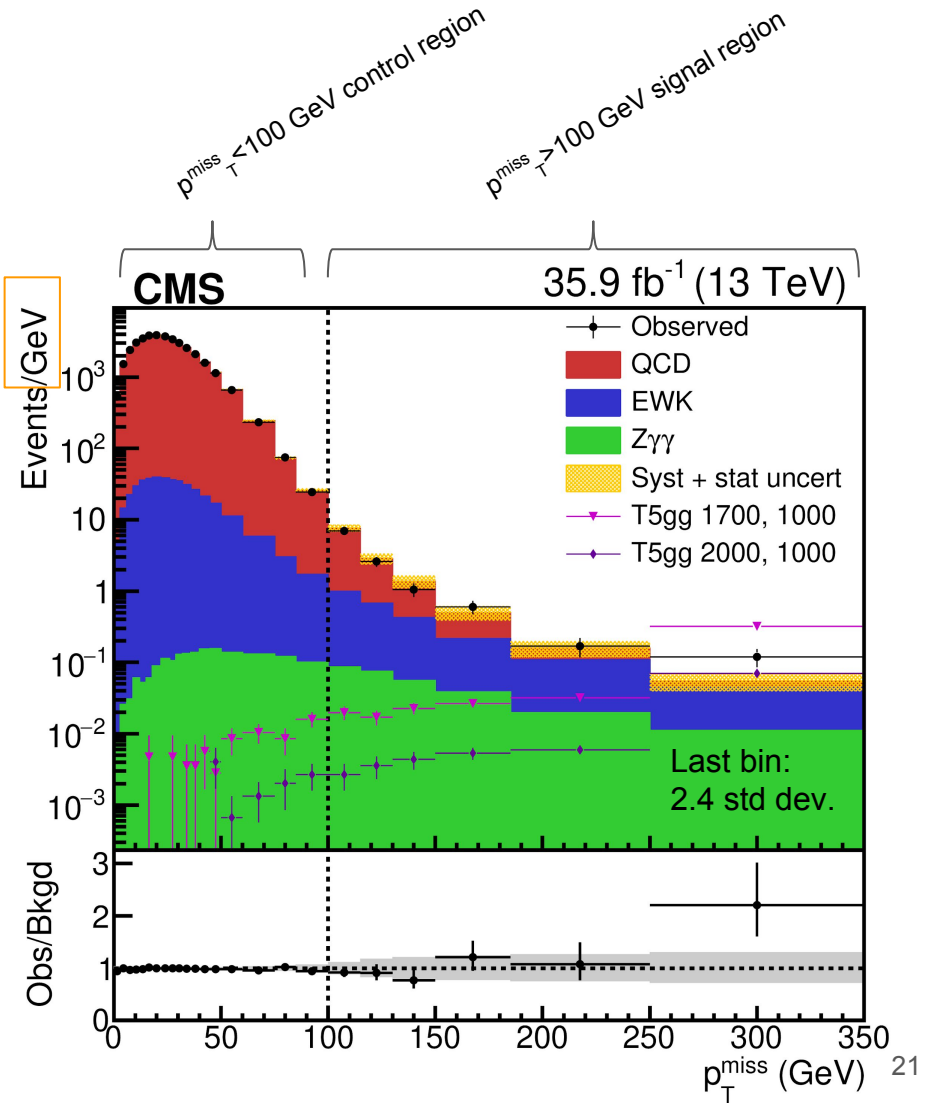
γ + MET in strong production SUS-17-011

Background estimation:

- QCD multijet background
  - **Fully data driven**
  - p^{miss}_T<100 GeV control region
  - Double fake photon control region
  - **ABCD like extrapolation**
  - Scaling factor runs as exp. as a function of p^{miss}_T
- EWK background
  - **Fully data driven**
  - Primary contribution: Wγ, W+jets
  - $\mathbf{f_{e\to\gamma}}$ **misidentification rate** from m_Z^{ee} and $m_Z^{e\gamma}$

    $f_{e\to\gamma} = N_{e\gamma} / (2N_{ee} + N_{e\gamma})$
  - Scaling the eγ control sample by

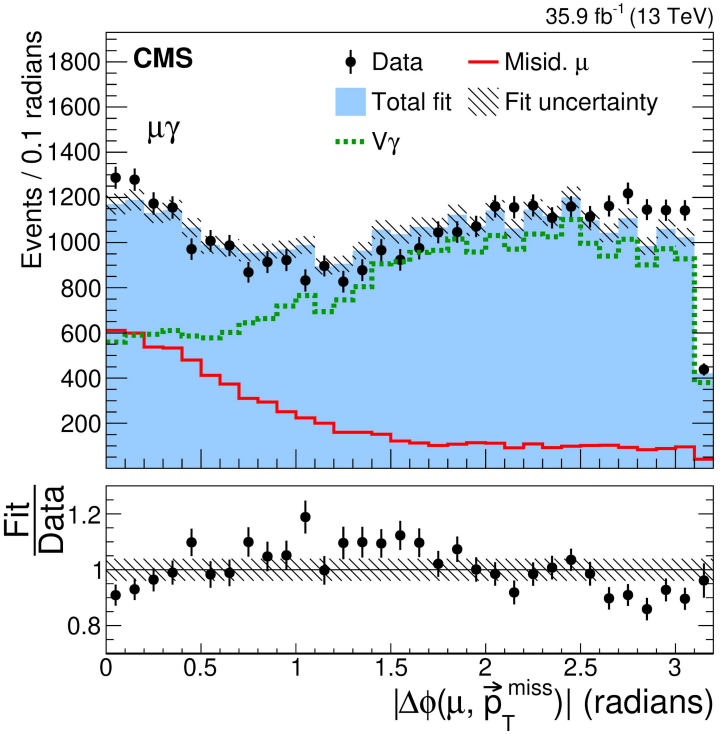
    $f_{e\gamma\to\gamma\gamma} = f_{e\to\gamma} / (1 - f_{e\to\gamma})$
- Z→ $\nu\nu$ background
  - Modeled using **NLO simulation**
  - Uncertainty of 50% is assigned to cover all systematics



γ + MET + lepton SUS-17-012

Background estimation:

- Misidentified photons (no genuine prompt photon)
  - Electron → Photon misidentification
  - Jet → Photon misidentification
- **Dominant: EWK & misidentified leptons** (lepton not from prompt W/Z decay or not lepton)
  - **Misidentified leptons**: non-iso lepton from hadron decay, photon conv, misidentified jets
  - Estimated by modifying the lepton definition → **control region**
    - Inverting the isolation requirement
    - For e the track matching and cluster shape are also inverted → cleaner hadronic signal
    - $|\Delta\phi(l, p_T^{miss})|$ and p^{miss}_T shape of this background are taken from the CR
  - **EWK:** main SM contributors are **Wγ and Zγ**
  - $|\Delta\phi(l, p_T^{miss})|$ distribution from Wγ and Zγ is determined from simulation
  - Overall normalization from **2 component template fit**
    - Performed in 40 < p^{miss}_T < 70 GeV after removing the misidentified photon and double vectorboson contributions
    - Results in a scale and a transfer factor

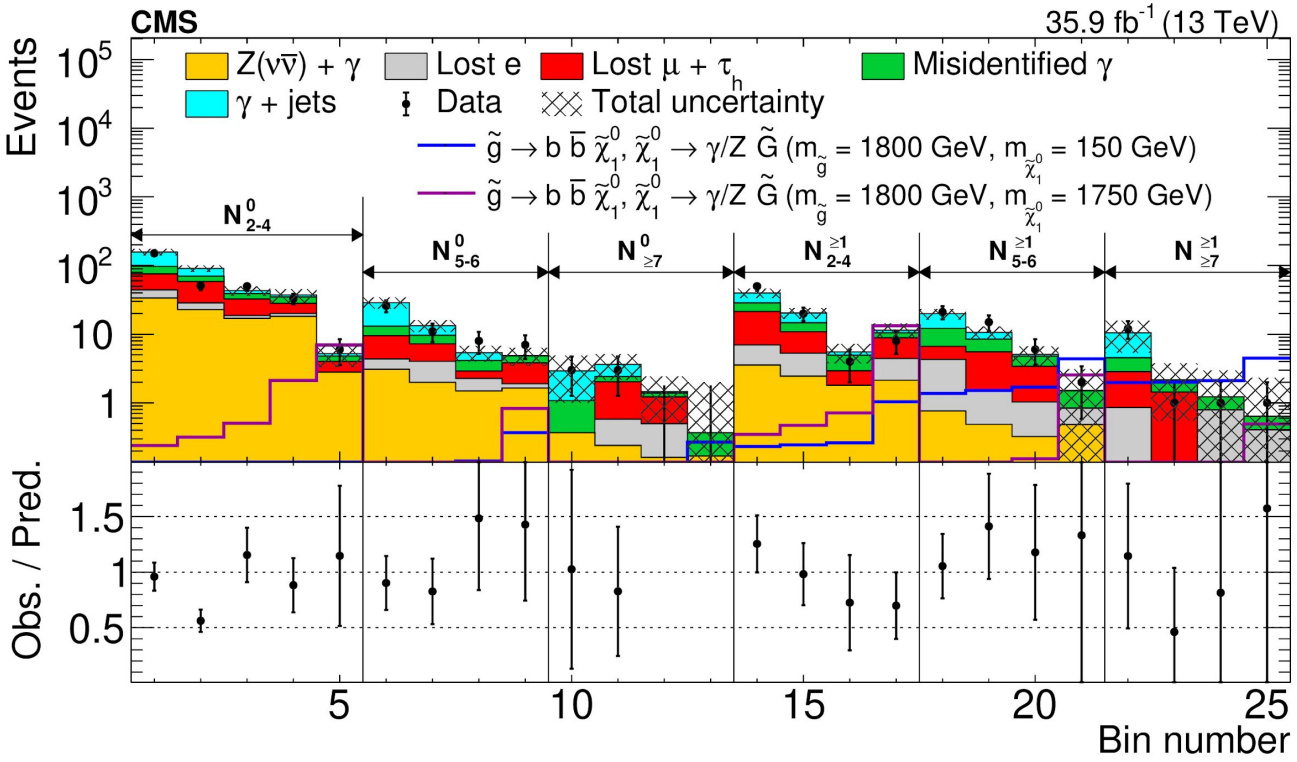


γ + MET + (b-)jets in strong production

SUS-18-003

Background estimation:

- Four main SM backgrounds:
  - High-p_T γ+ W or Z decaying leptonically → lost lepton or hadronic τ decay
  - W → eν and the e is identified as a γ
  - Zγ → $\nu\nu\gamma$
  - QCD multijet: jet p_T mismeasurement + jet misidentified as γ



γ + MET + (b-)jets in strong production

SUS-18-003

Background estimation:

- Four main SM backgrounds:
  - High-p_T γ+ W or Z decaying leptonically → lost lepton or hadronic τ decay
  - W → eν and the e is identified as a γ
  - Zγ → $\nu\nu\gamma$
  - QCD multijet: jet p_T mismeasurement + jet misidentified as γ
- Example: Zγ → $\nu\nu\gamma$
  - Shape of $p^{miss}_T(N_{jets})$ for Zγ → $\nu\nu\gamma$ is modelled in simulation
  - Normalization is measured in Zγ → $\ell^+\ell^-\gamma$ data using
    - Branching ratios & reco. efficiencies considered
    - Exactly 2 oppositely charged same flavour leptons
    - p_T>100 GeV
    - 80 GeV< $m_{\ell\ell}$<100 GeV
  - Contamination from ttγ in the Zγ → $\ell^+\ell^-\gamma$ control region is estimated using a different flavoured control region