SUSY searches with photons at LHC with the CMS detector

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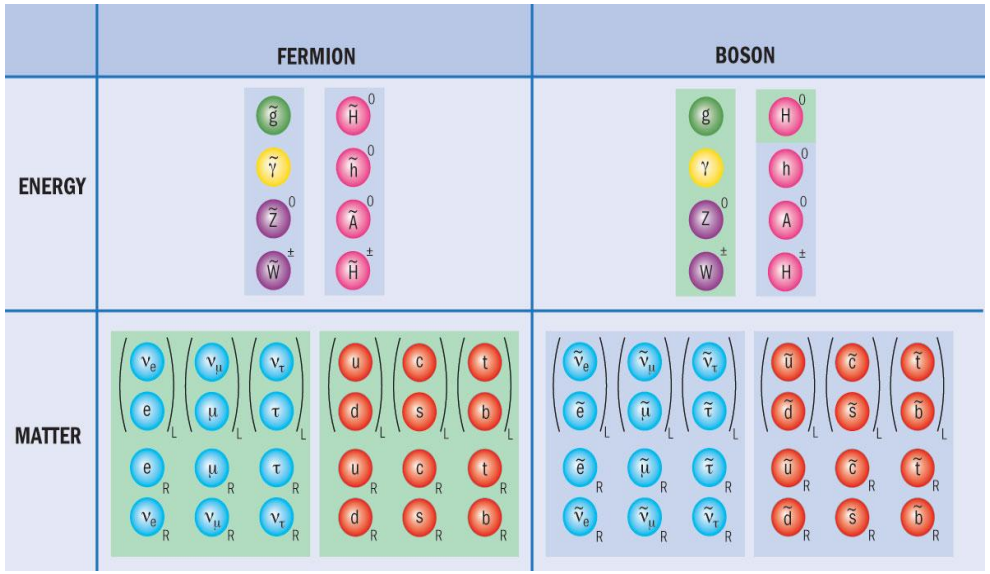
Introduction

Results from 4 recent analyses + 1 combination addressing GMSB / GGM

- JHEP 06 (2019) 143A: two photons and missing transverse momentum
  Strong gluino and squark production: T5gg, T6gg
- JHEP 01 (2019) 154: a photon, a lepton and missing transverse momentum
  Strong gluino and squark production: T5Wg, T6Wg;
  Electroweak chargino - neutralino production: TChiWg
- arXiv:1907.00857: combined search with photons and missing transverse momentum
  GGM interpretation
- Eur. Phys. J. C 79 (2019) 444: a photon, jets, b-jets and missing transverse momentum
  Strong gluino and stop production: T5qqqqHG, T5bbbbZG, T5ttttZG, T6ttZG
- arXiv:1908.08500: Higgs boson to diphoton decay
  Electroweak neutralino production TChiHH, TChiZH

Supersymmetric models



- Spacetime symmetry relating fermions and bosons
- Predicts superpartners for every SM particle
- No SUSY partner with SM mass discovered yet
  → SUSY broken
- Minimal Supersymmetric Standard Model (MSSM)
  adds >100 parameters
- Spontaneous symmetry breaking in a hidden sector mediated by some interaction to the visible sector
  - Mediator = gravity → Minimal Supergravity (~5 parameters)
  - Mediator = gauge interactions
    → Gauge Mediated Supersymmetry Breaking (GMSB, ~5 parameters)
    → General Gauge Mediation (GGM, ~8 parameters)
- Study simplified models concentrating on a single SUSY process with its cross-section, BR and the masses of the sparticles considered as model parameters: results on $\sigma \cdot BR$

R-parity and Lightest SUSY Particle

R-parity conservation **assumed** to suppress couplings leading to baryon and lepton number violation

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

→ **SUSY particles produced in pairs**

→ **Lightest supersymmetric particle (LSP) is stable**

In GMSB / GGM with R-parity conservation

- **LSP**: light (<1 GeV) **gravitino** (dark matter candidate)
- **Next-to-LSP** (NLSP): typically a **neutralino** which can be bino-, wino-, higgsino-like
- Lightest neutralino and chargino can be mass-degenerate
- NLSP assumed to decay as: $\tilde{\chi}_0 \to \tilde{G} + \gamma/Z/H \quad (\tilde{\chi}^{\pm} \to \tilde{G} + W^{\pm})$

Experimental observables

Missing Transverse Momentum (MET): Momentum imbalance of all observed physics objects

- SM: neutrinos, jet momentum mismeasurement
- MSSM: weakly interacting LSP, eg. gravitinos

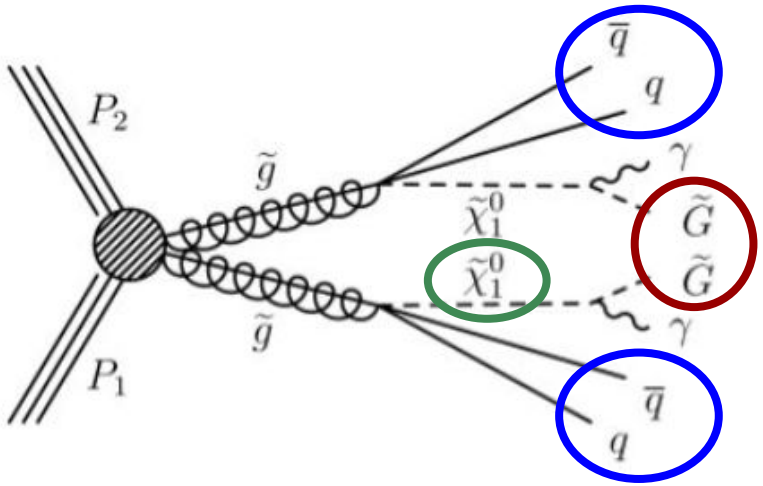
Large Hadronic Activity (H_T): Many reconstructed jets in strong SUSY production

$$H_T = \sum |p_T^{\text{jet}}(i)|, \quad H_T^{\gamma} = |p_T^{\gamma}| + \sum |p_T^{\text{jet}}(i)|$$

Reconstructed Photon-MET system to characterise NLSP:

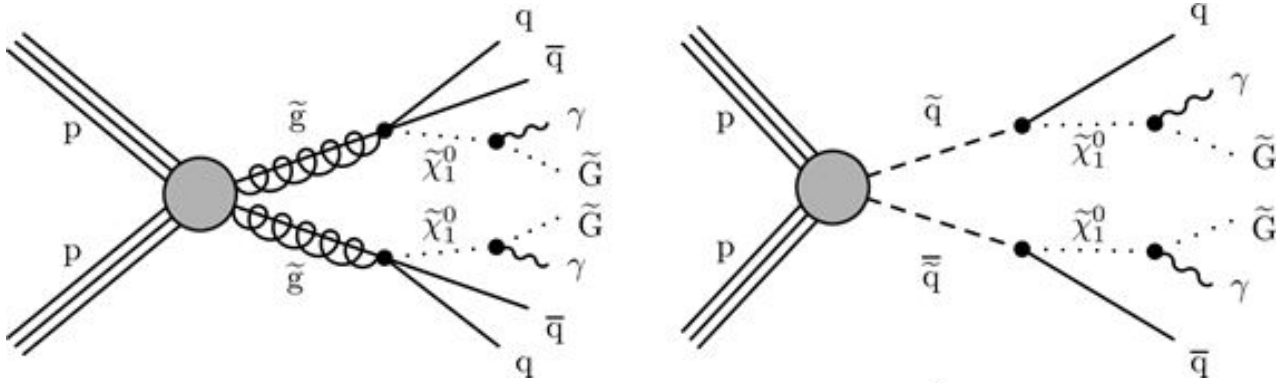
- Transverse energy scalar sum: $S_T^{\gamma} = \sum_i E_T^{\gamma i} + E_T^{miss}$
- Invariant mass:

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



JHEP 06 (2019) 143A

γγ + MET

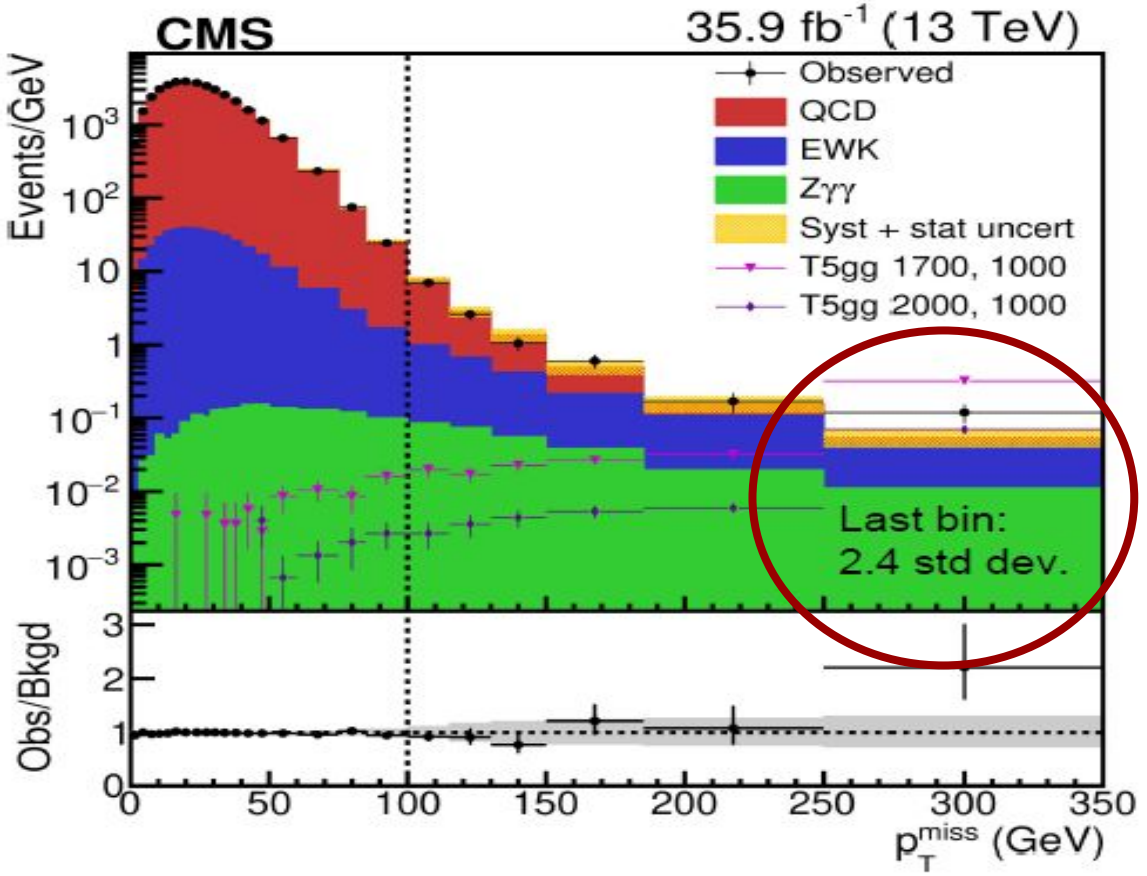


Event selection

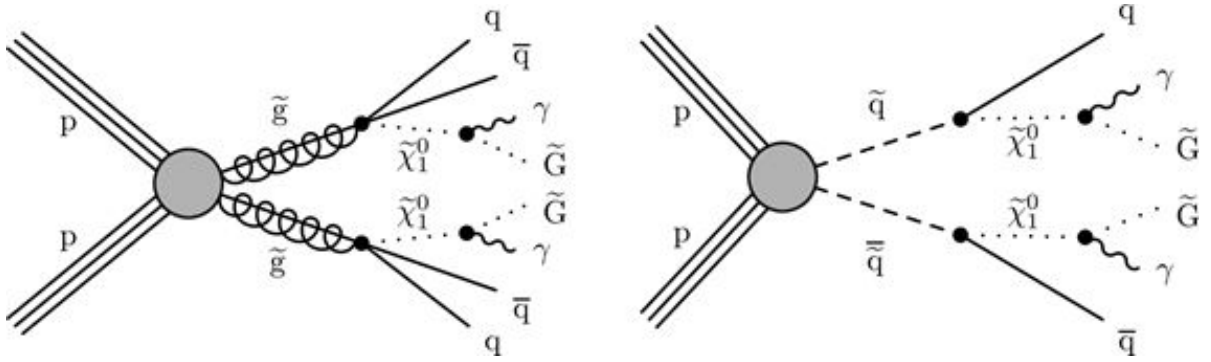
- Diphoton trigger
- Two photons with pT > 40 GeV
- Large diphoton mass m > 105 GeV
- Significant MET p_T^{miss} > 100 GeV
- No lepton with p_T > 25 GeV

Main backgrounds estimated from data

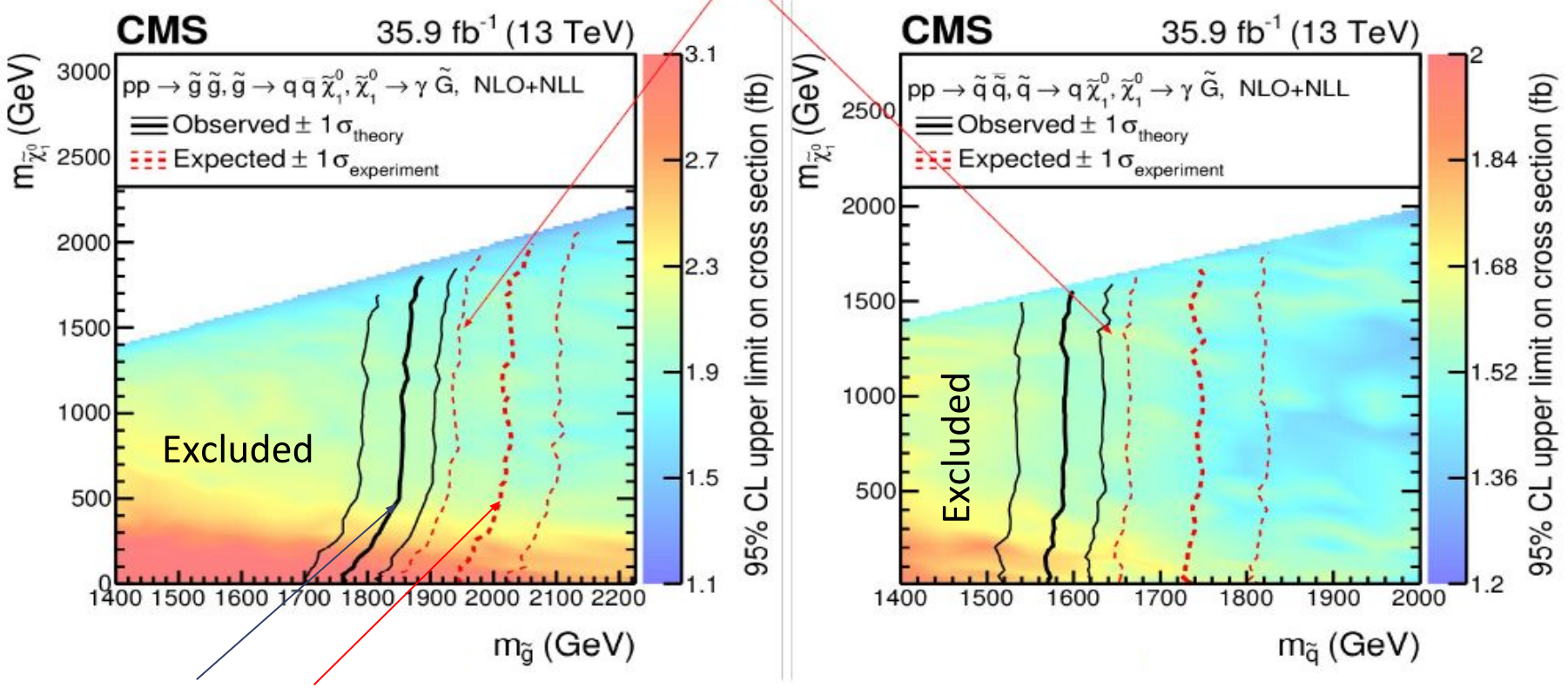
- QCD from ABCD method
- EWK (Wγ, W+jets) using e→γ misID rate



γγ + MET



Effect of last bin upward fluctuation



$\sigma_{theory} > \sigma_{observed\_upper\_limit}$ $\sigma_{theory} > \sigma_{expected\_upper\_limit\_no\_signal}$

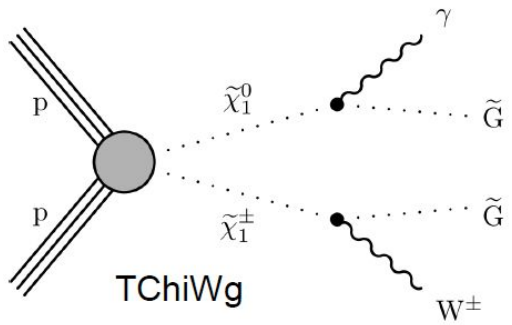
>200 GeV improvement for observed mass limit for both models with 8 TeV result

Gluino mass > 1.86 TeV

Squark mass > 1.59 TeV

JHEP 01 (2019) 154

γ + MET + lepton



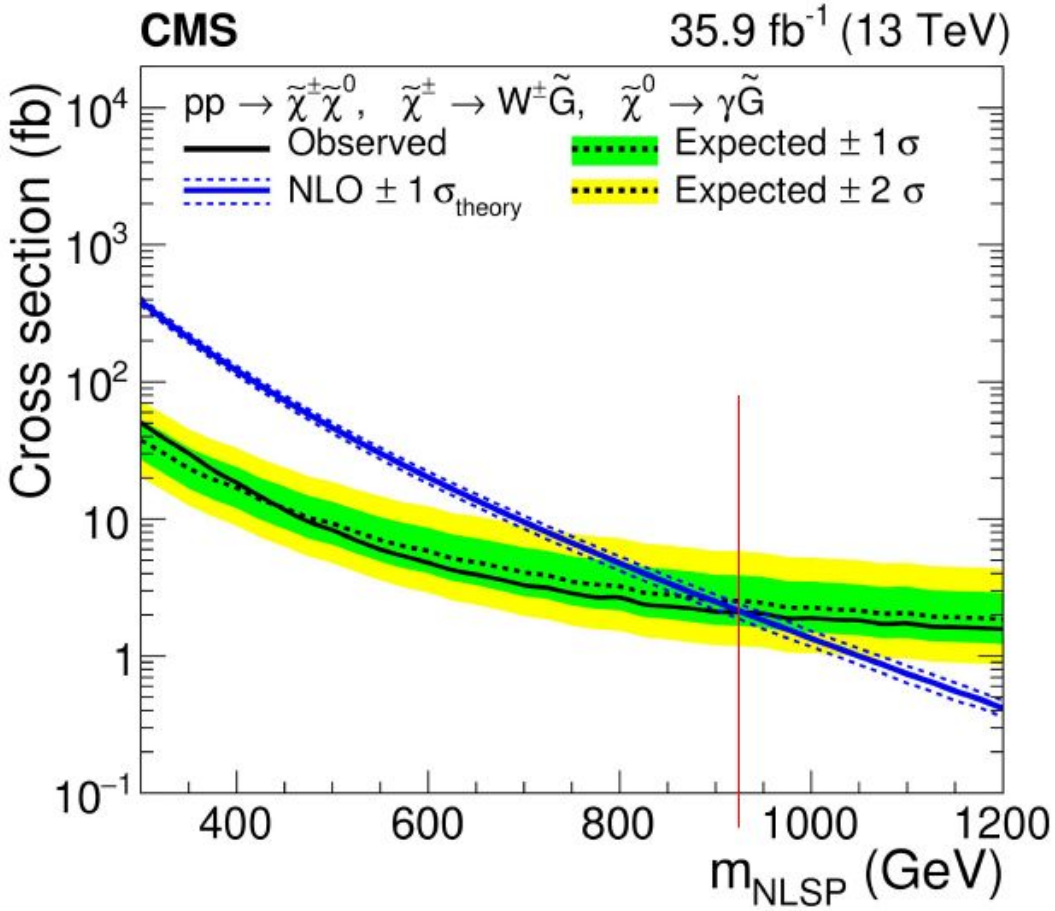
Sensitive to strong gluino and squark pair production as well as **EW chargino - neutralino production**

Background from various sources :

- misidentified photons either from electron or jet (data-driven)
- W/Z + γ (shape from simulation)
- rare diboson + γ and ttγ (from simulation)
- misidentified leptons (shape from non-iso lepton CR)

No excess ⟶ expected and observed limits in agreement

Neutralino mass > 930 GeV



GGM Combination arXiv:1907.00857

Four analyses looking for photon + MET combined

- previous two analyses in this talk:
  γγ + MET, γ + MET + lepton
- Phys. Lett. B 780 (2018) 118: electroweak γ + MET
- JHEP 12 (2017) 142: strong γ + MET + H_T

Overlaps removed using additional physics object vetos

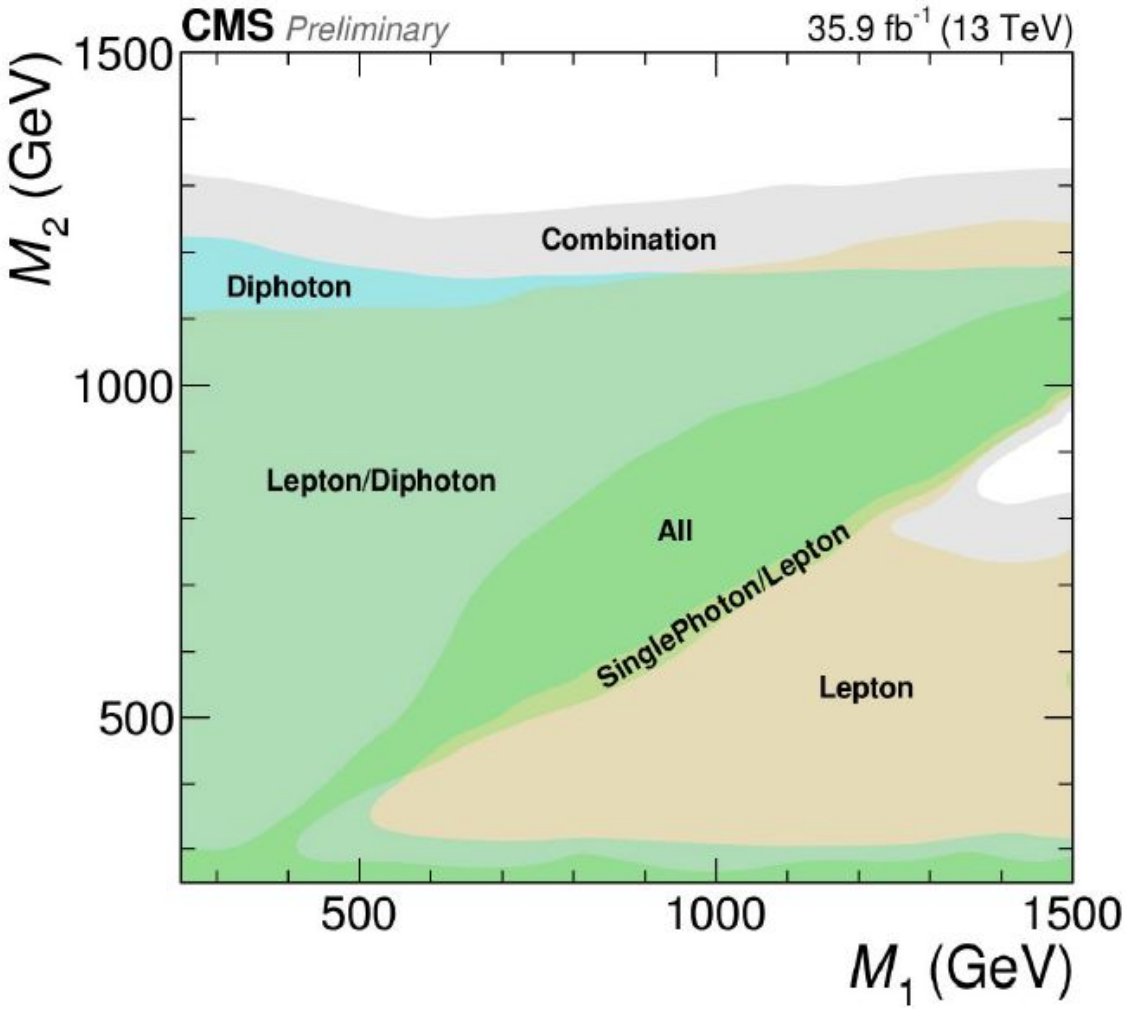
Interpret simplified model results in a full SUSY model

Present limits on model parameters

- bino mass parameter **M_1 > 1400 GeV**
- wino mass parameter **M_2 > 1300 GeV**

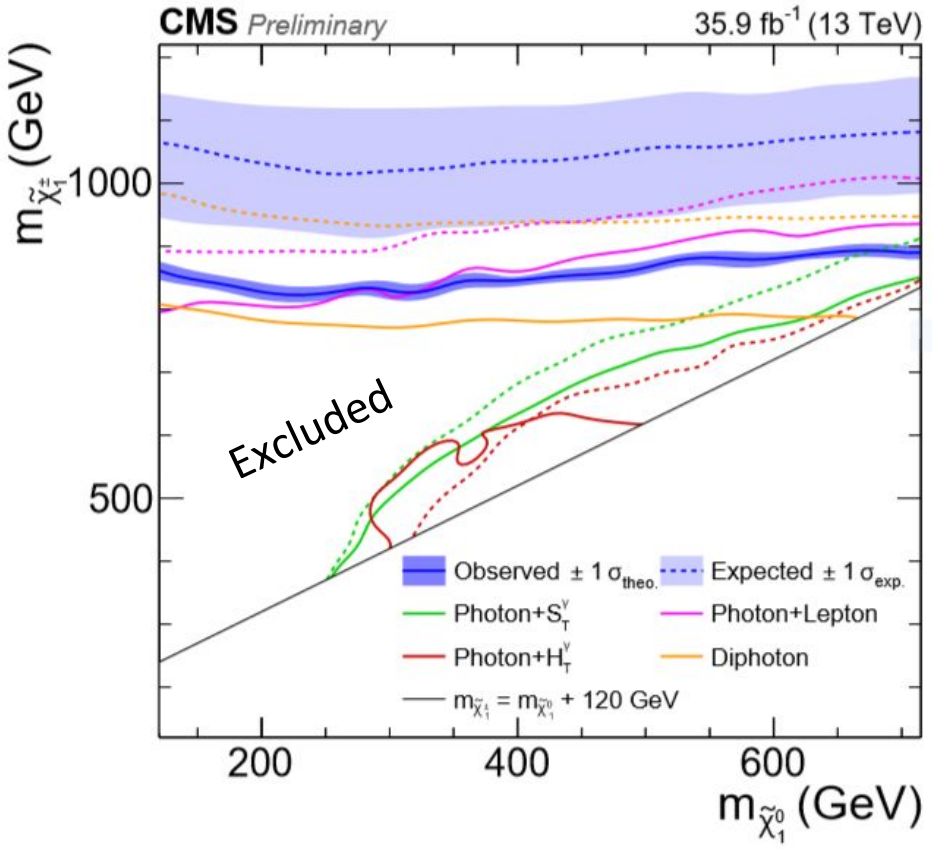
(other parameters are fixed to typical values)

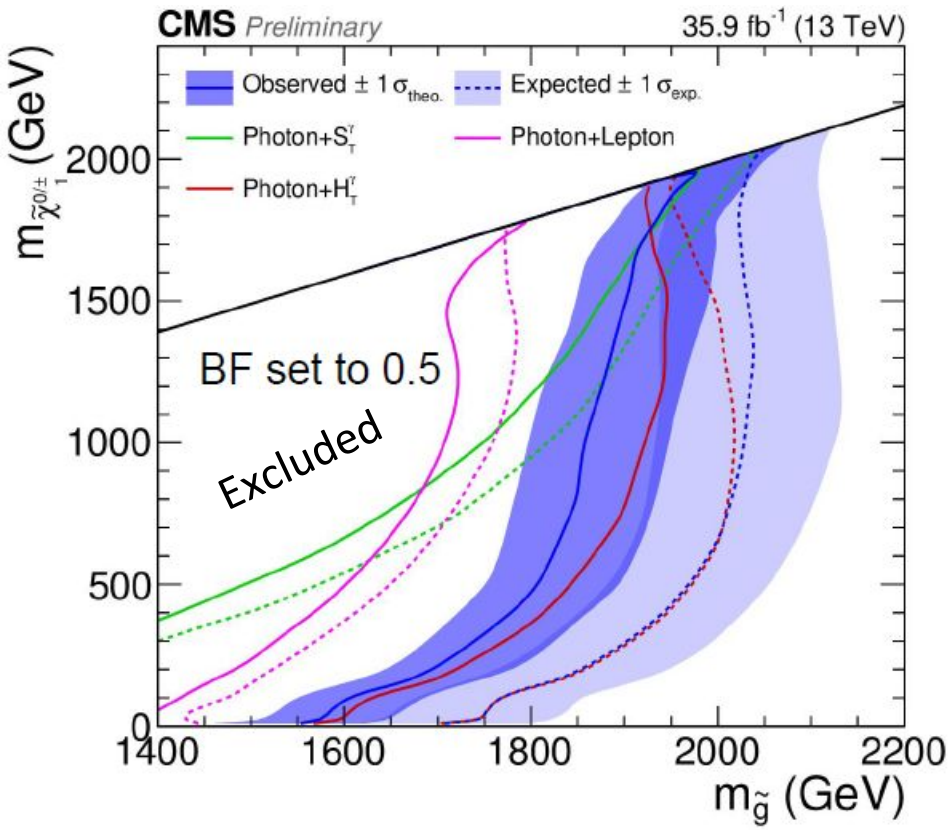
Combination improves sensitivity by ~100 GeV



GGM Combination

Results can also be translated to limits on physical SUSY particle masses
Worse than expected limit due to excess in γγ + MET (JHEP 06 (2019) 143A) analysis



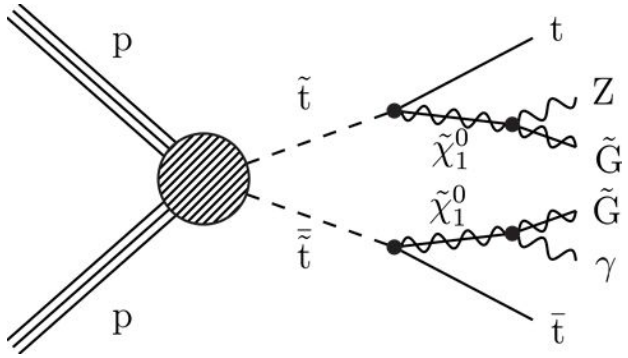


Chargino mass > 890 GeV

Gluino mass > 1950 GeV

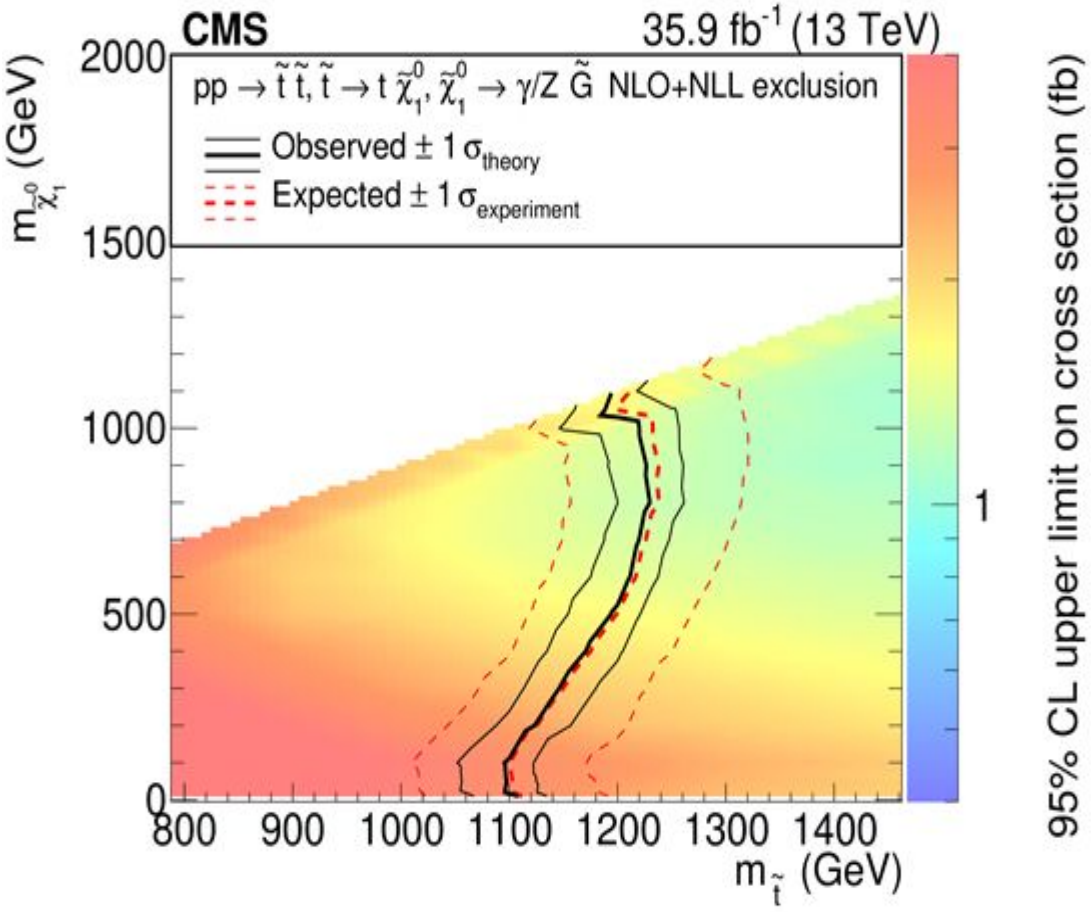
Eur. Phys. J. C 79 (2019) 444

γ + jets + b-jets + MET



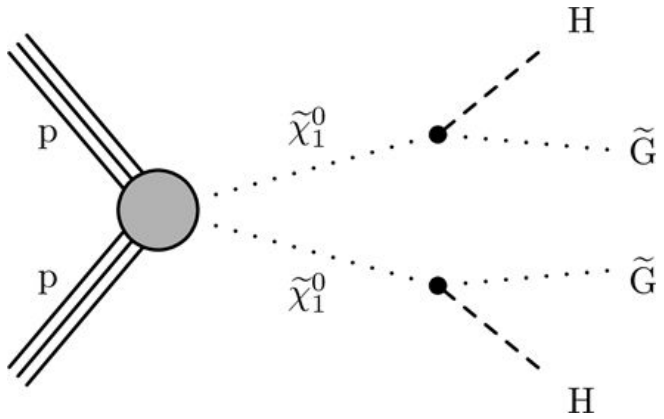
- Sensitive to gluino and squark (stop) pair production with b quark(s) in the final state
  - produced directly from gluino or from H, Z → bb, t → bW decays
- No excess → good agreement between expected and observed exclusion
- Limits tend to degrade at extremes due to less jets or less MET in these regions

Stop mass > 1110 GeV



arXiv:1908.08500

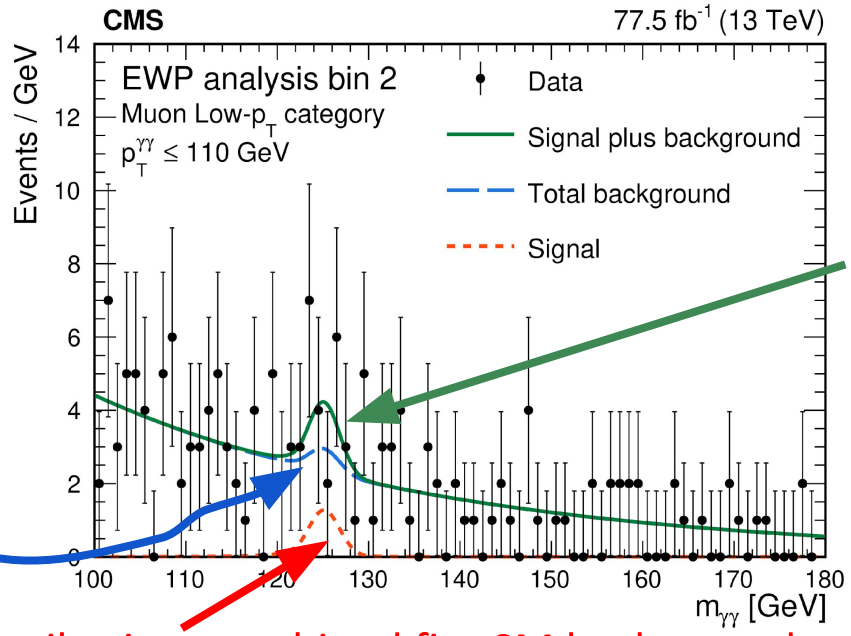
H → γγ from neutralino



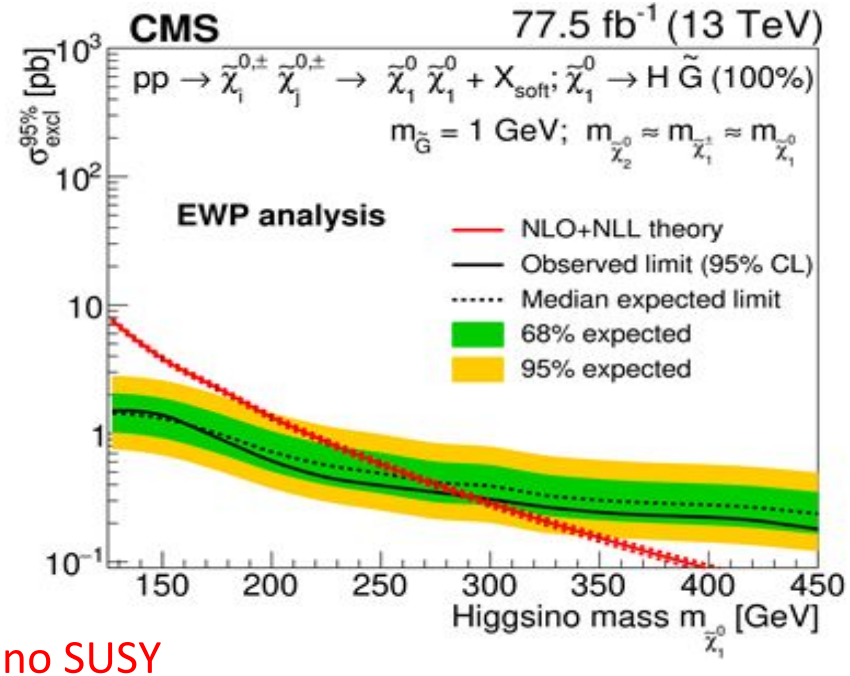
- Reconstruct Higgs boson H → γγ candidates
- Use charged leptons and b jets to tag the other bosons (Z or H)
- Look for additional Higgs boson signal over the SM expectation: fitted signal consistent with zero

Higgsino mass > 290 GeV

SM background: side-band fit to diphoton mass distribution + SM Higgs production from theory



Combined fit of SM background + SUSY signal



Possible SUSY contribution: combined fit - SM background ~ consistent with no SUSY

Summary

- Searches address a large area of the GMSB (GGM) MSSM parameter space
- Results mostly consistent with SM (largest excess at 2.4σ level in $\gamma\gamma$+MET search)
- Provided limits on SUSY model parameters, particle masses
- Efforts are made to combine different simplified searches in GGM
- No signs of SUSY yet but it could still be hiding at many places
  - Only ~5% of the full planned pp integrated luminosity recorded yet
- Look out for exciting discoveries in the future with the (High-Luminosity) LHC

Backup

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**, |η|<1.44, **ΔΦ(ℓ,γ)>0.3** Distance between leading p_T photon and lepton **ΔR>0.8**	
Lepton:	**p^{ℓ}_T>25 GeV**	
	1.44<|η|<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:

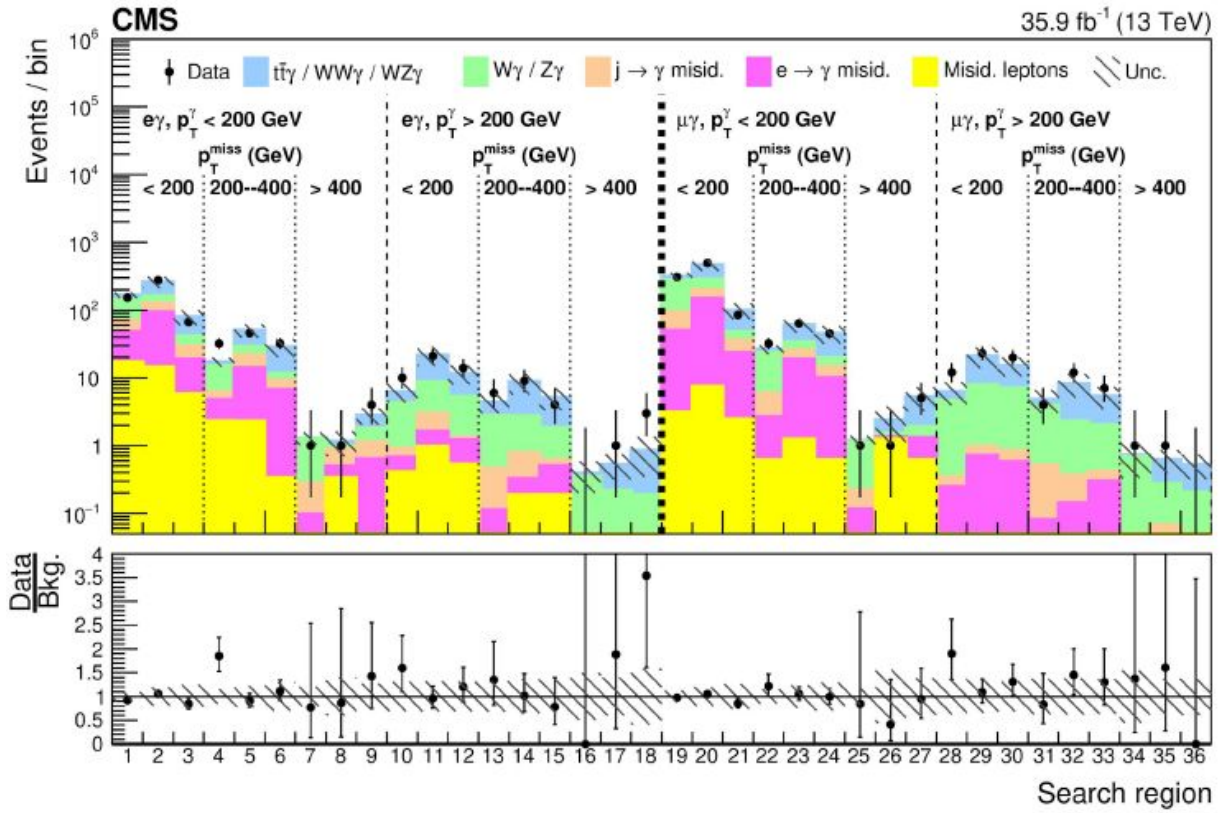
$$p_T^{\gamma}, p_T^{miss}, H_T$$

-> 2 × 18 bin

γ + MET + lepton SUS-17-012

Background estimation:

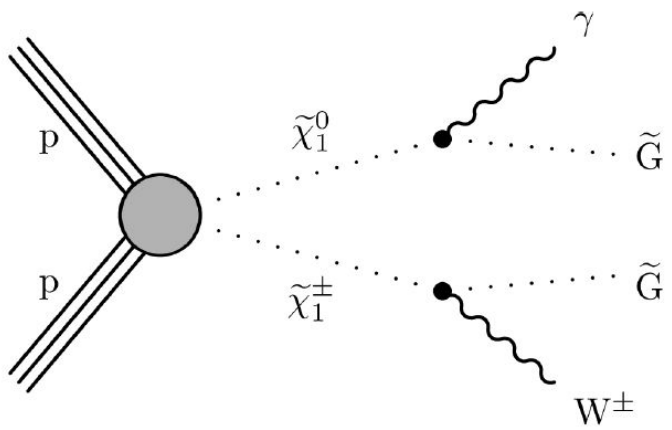
- Misidentified photons (no genuine prompt photon)
  - Electron ⟶ Photon (data driven, rate from Z tag-and-probe)
  - Jet ⟶ Photon (semi data driven)
- EWK & misidentified leptons (lepton not from prompt W/Z decay or not lepton)
  - EWK: Wγ, Zγ (shape from simulation)
  - Rare EWK: diboson+γ or ttγ (simulation)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

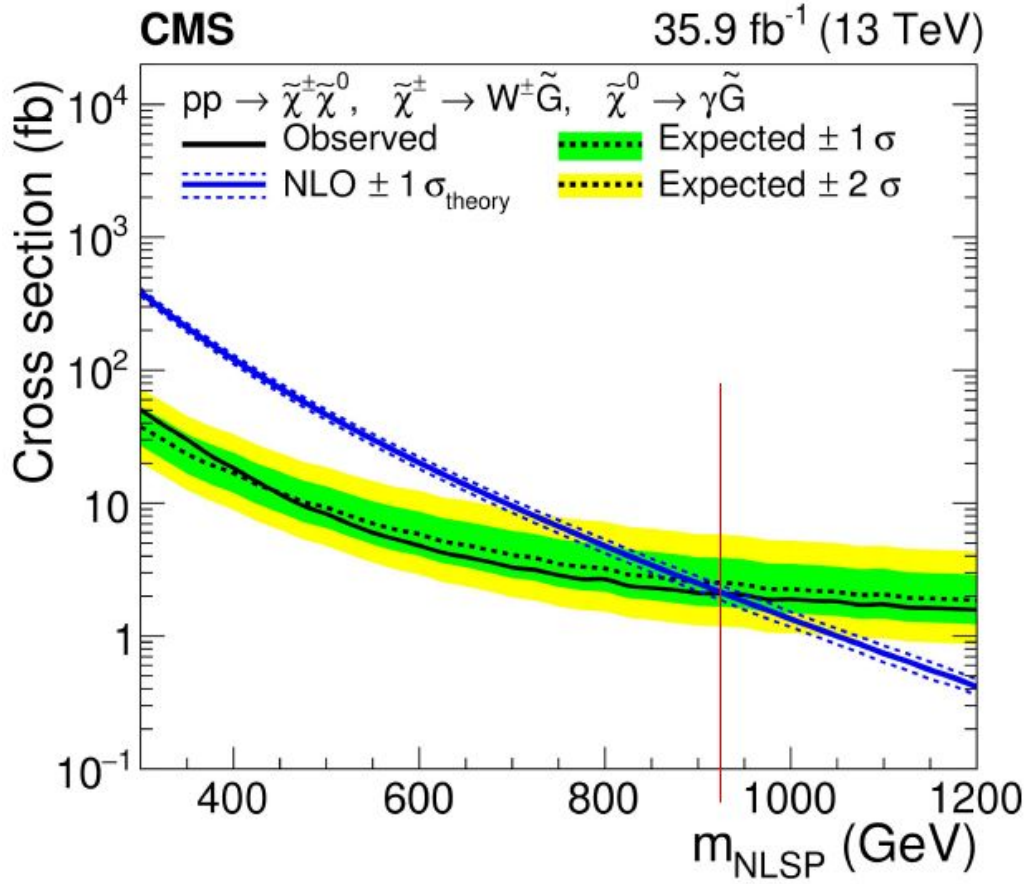


γ + MET + lepton SUS-17-012

EWK channel results:

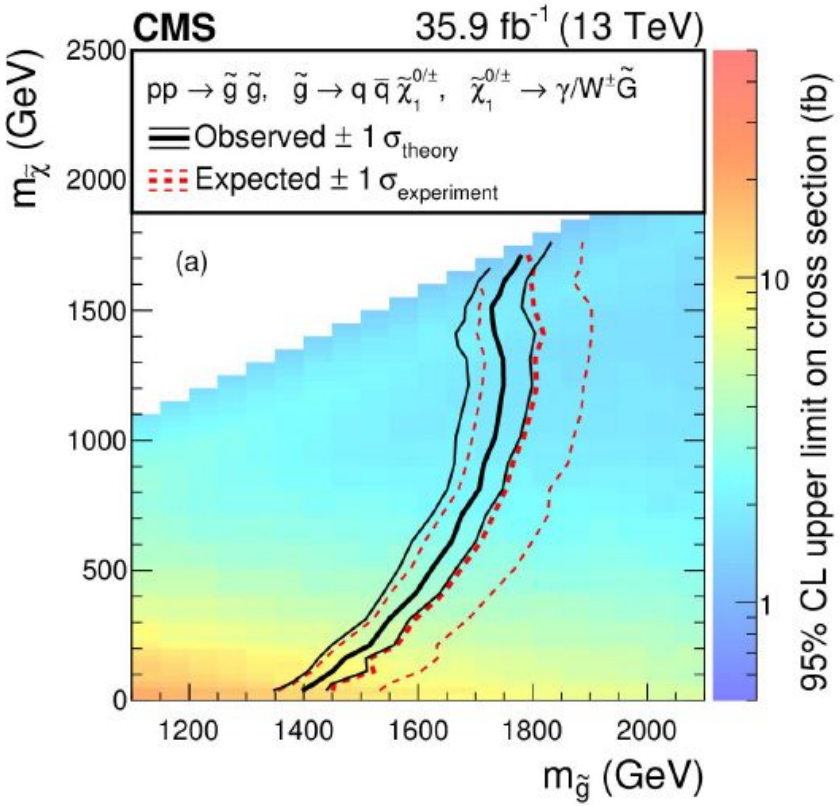
- Limit on NLSP mass in the TChiWg model
- 930 GeV (150 GeV improvement)
- Expected and observed exclusions are in good agreement

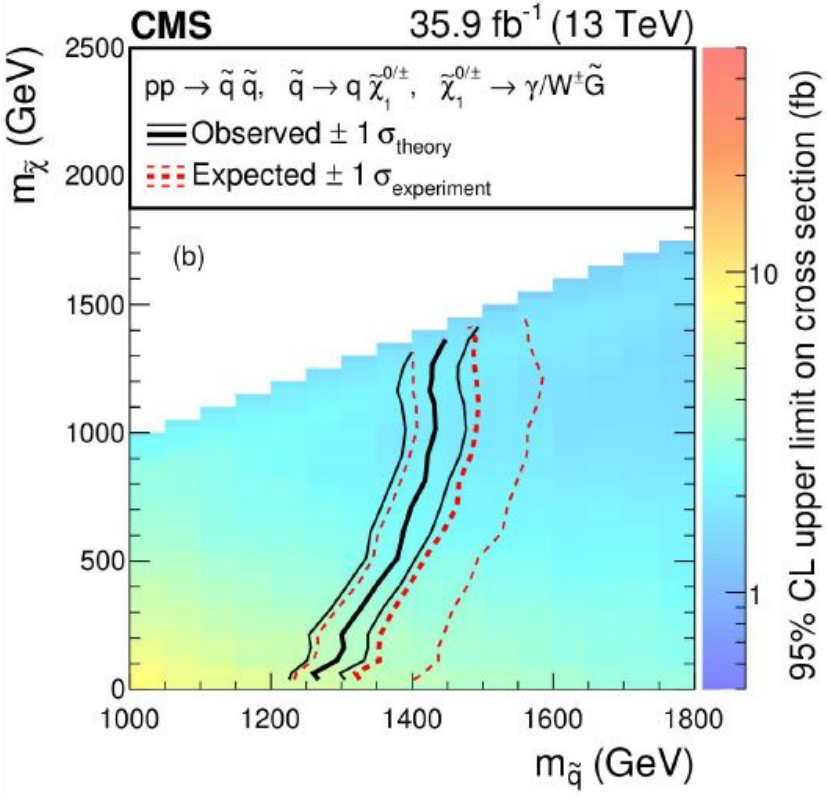




γ + MET + lepton SUS-17-012

Strong channel results:





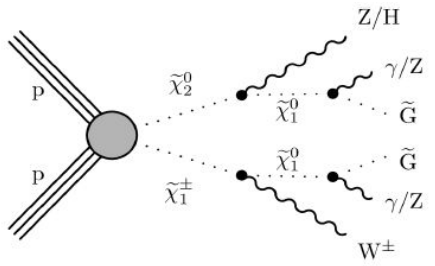
Up to 1.75 (1.43) TeV

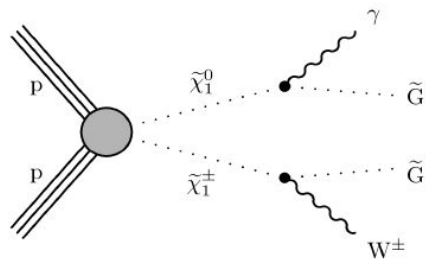
GGM Combination CMS-PAS-SUS-18-005

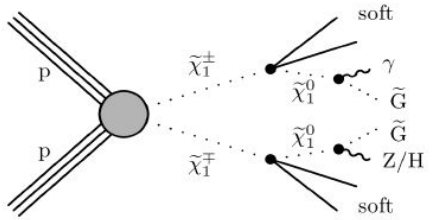
- Framework: GGM
- Data used: 35.9 fb-1
- Four analyses combined:
  - Previous two in this talk
  - Other 2 were presented at DIS2018:

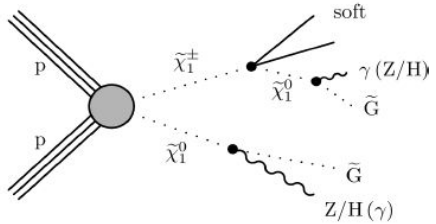
    → SUS-16-046: electroweak SUSY productions with photons + MET

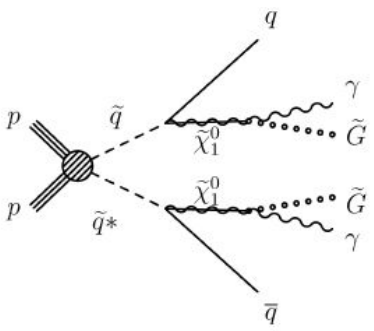
    → SUS-16-047: strong SUSY productions with photons + MET + large transverse hadronic activity
  - Overlaps removed in an optimized way using additional vetos

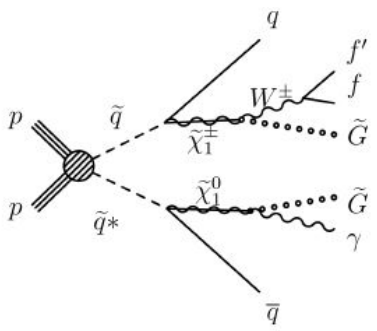


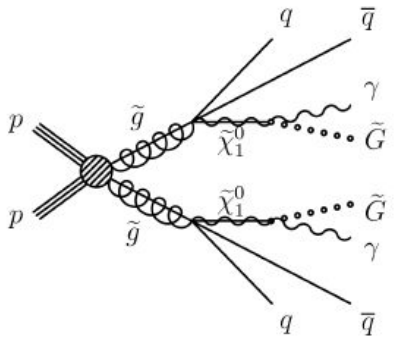


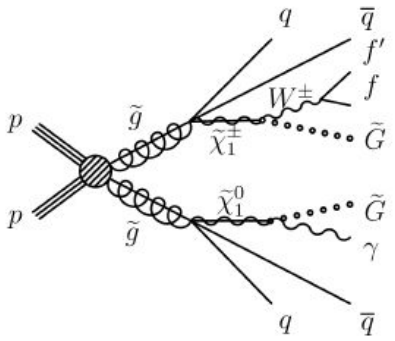




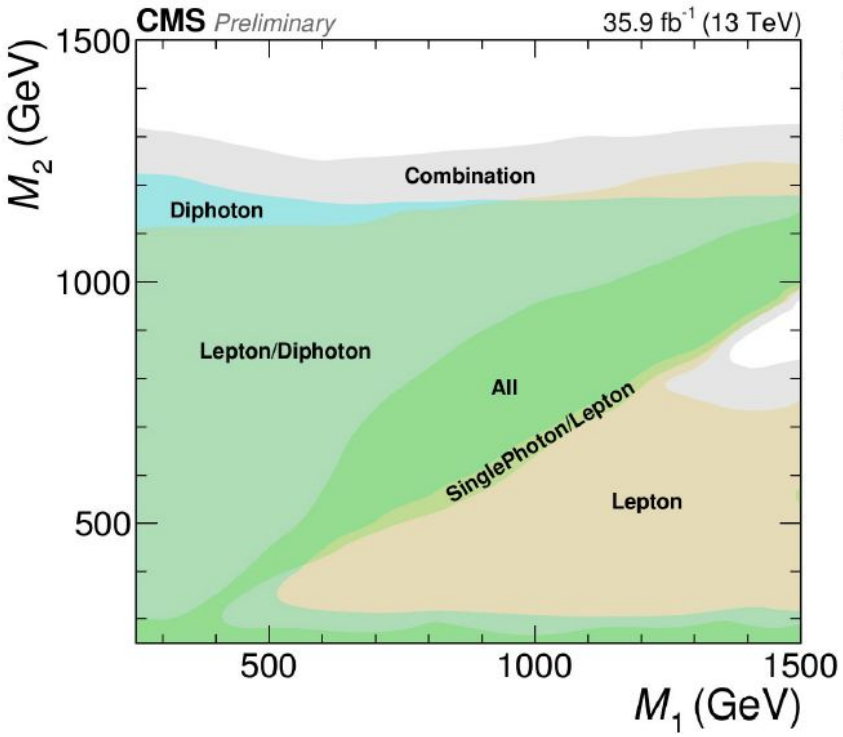


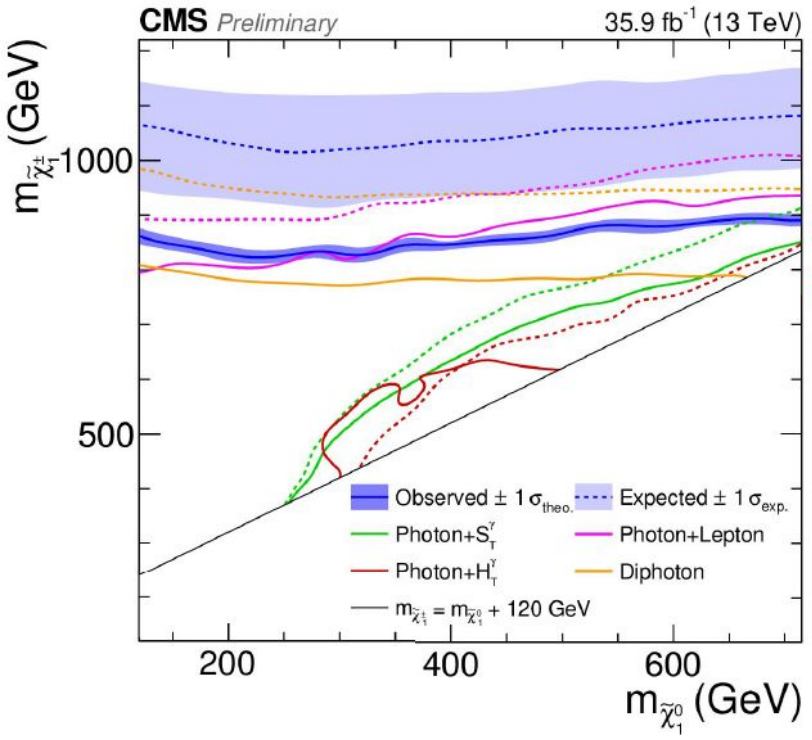


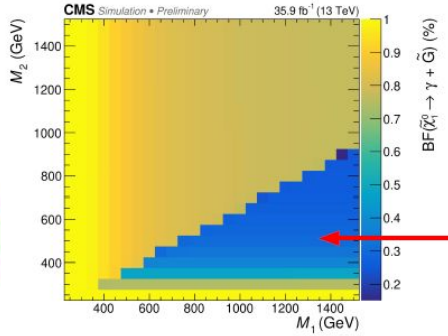




GGM Combination CMS-PAS-SUS-18-005

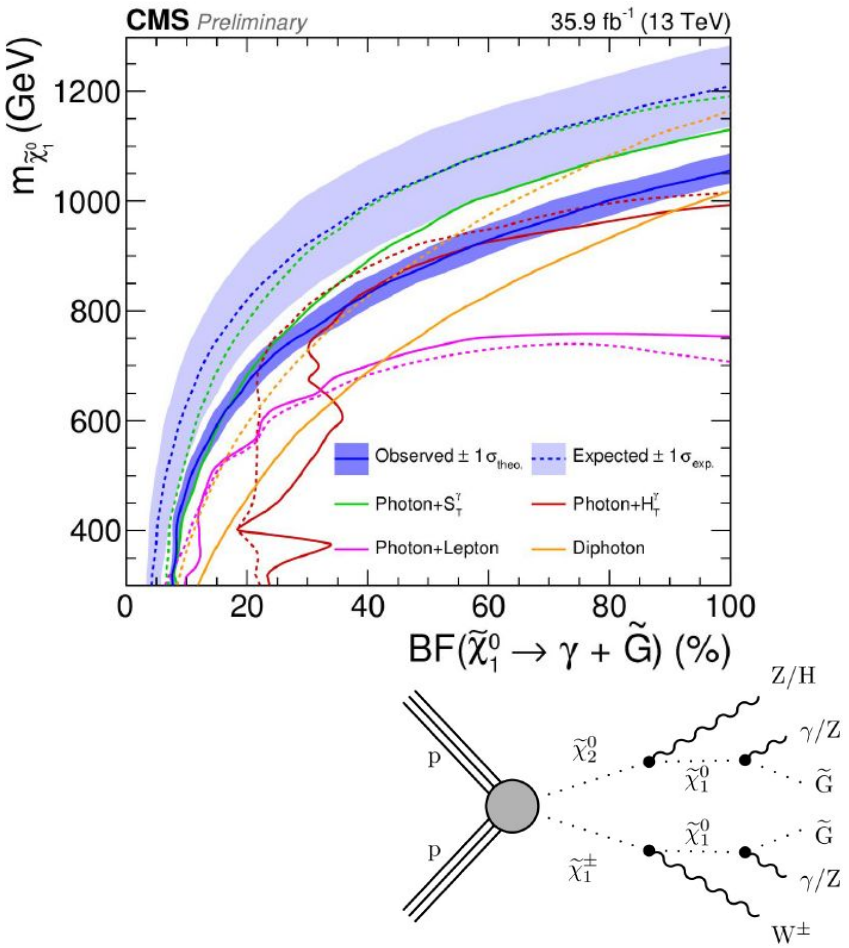


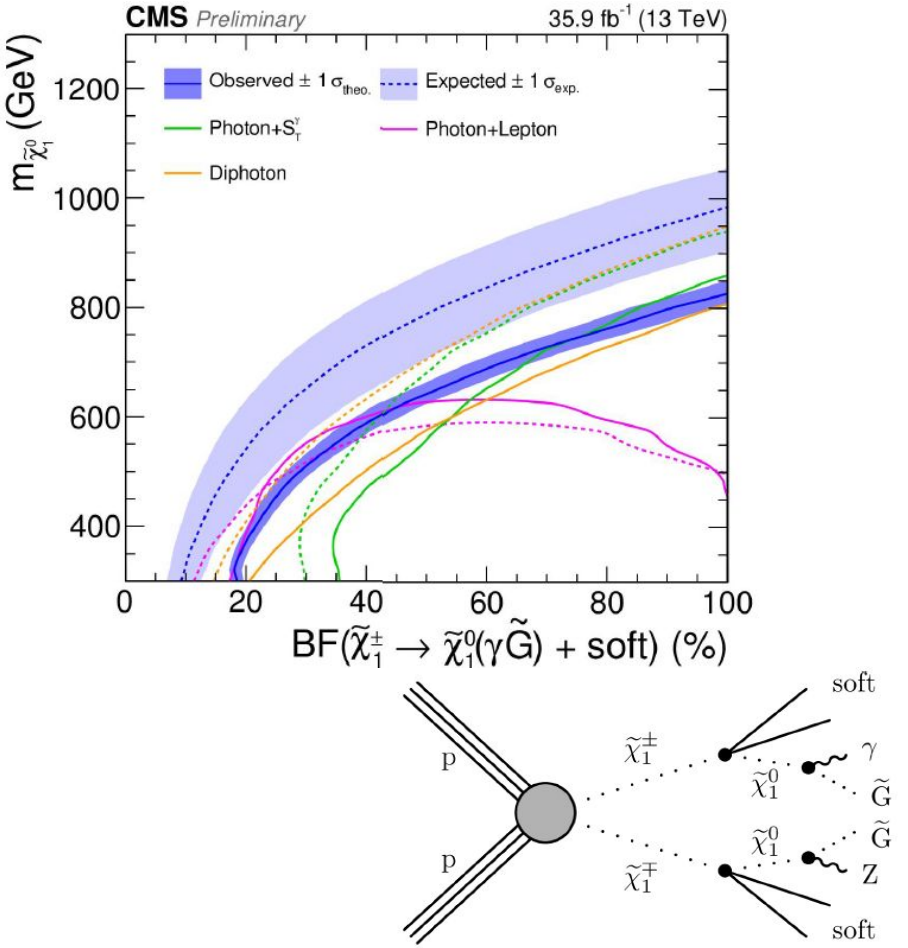




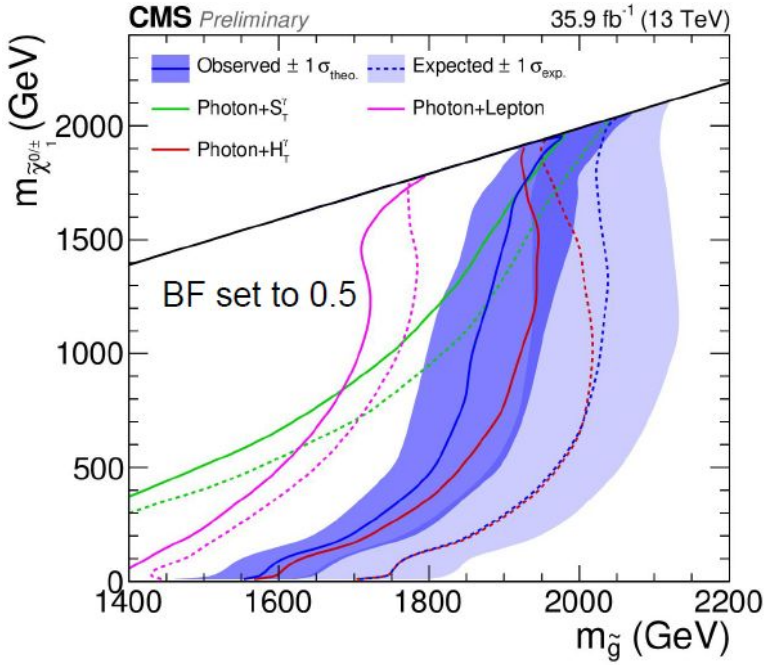
Wino like NLSP

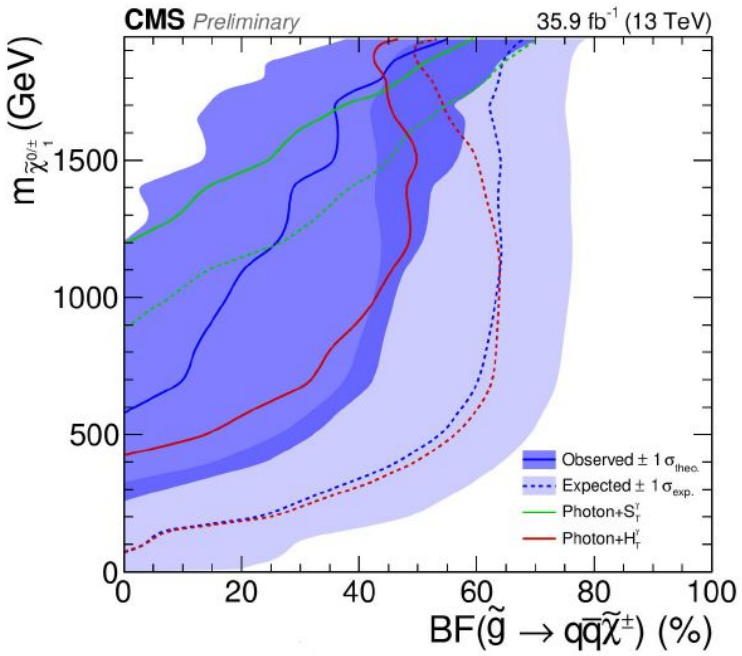
GGM Combination CMS-PAS-SUS-18-005



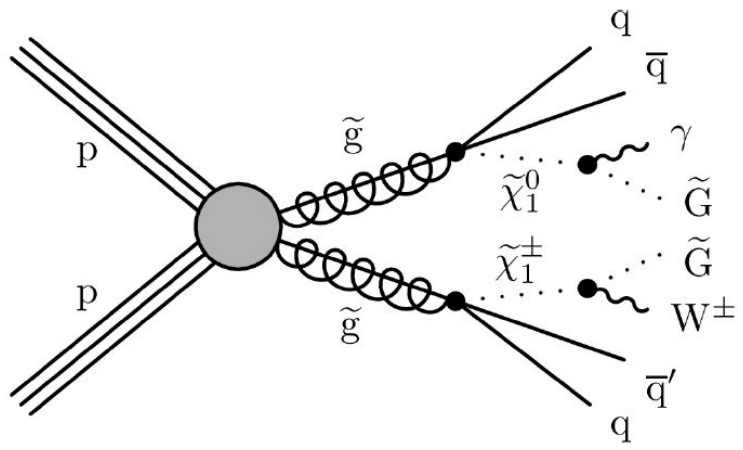


GGM Combination CMS-PAS-SUS-18-005





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

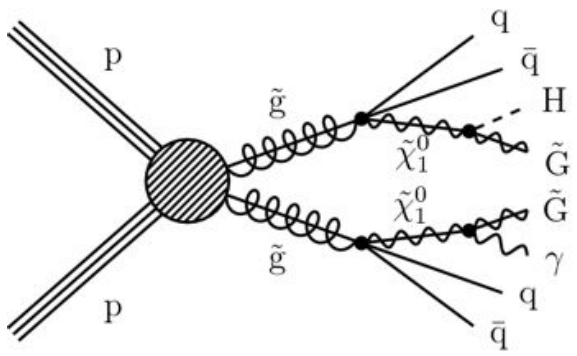


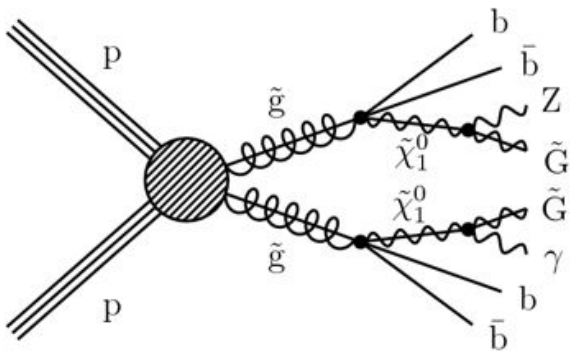
γ + MET + (b-)jets in strong production SUS-18-002

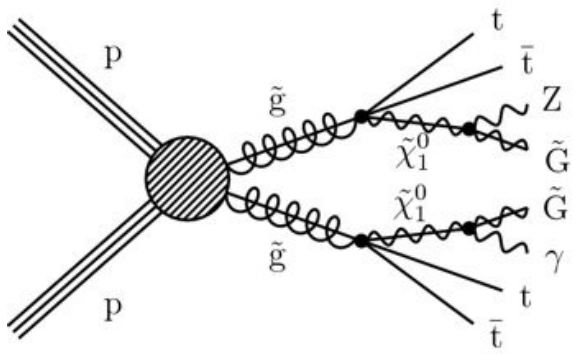
- Framework: GGM
- Process:
  - Gluino pair production
  - Stop pair production
- Data used: $35.9\ fb^{-1}$

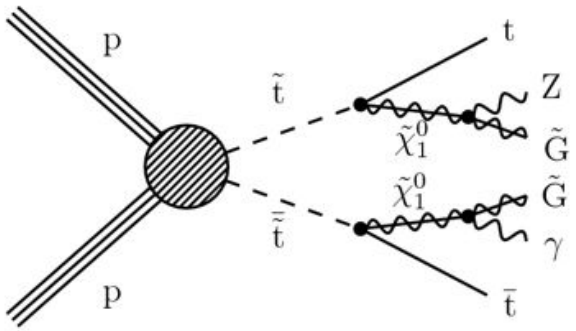
Event selection:

- Photon trigger
  - $p_T^{\gamma} > 90$ GeV if $H_T^{\gamma} > 600$ GeV
- Photon:
  - $p_T^{\gamma} > 40$ GeV for both
  - $m_{\gamma\gamma} > 105$ GeV
- $p_T^{miss} > 100$ GeV
- Vetos:
  - Muon: $p_T > 25$ GeV, $|\eta| < 2.4$
  - Electron: $p_T > 25$ GeV, $|\eta| < 2.5$









γ + MET + (b-)jets in strong production SUS-18-002

Backgrounds:

Lost ℓ or hadronic τ decay

- 1ℓ CR, TF ← MC
- τ from BF

W $\rightarrow$ eν and e $\rightarrow$ γ

- 1e, 0 γ CR, TF ← MC

Zγ $\rightarrow$ $\nu\nu\gamma$

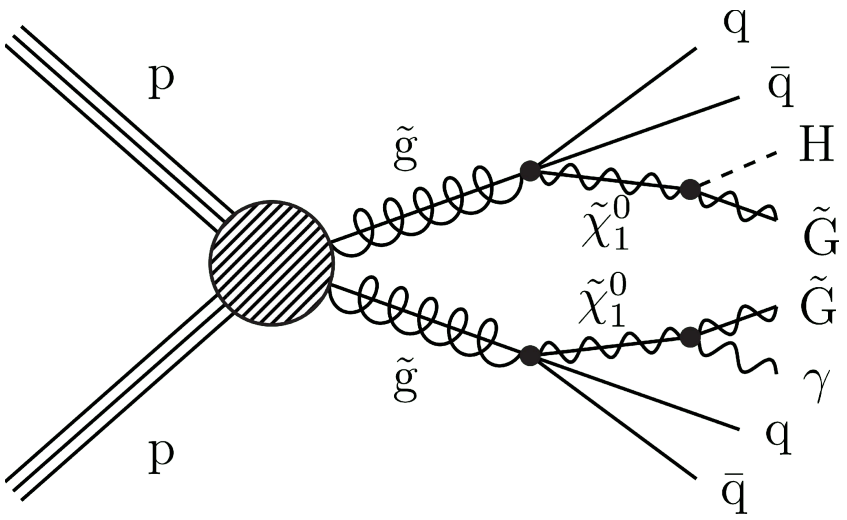
- Shape from MC
- Normalization: Z(ℓ+ℓ-)

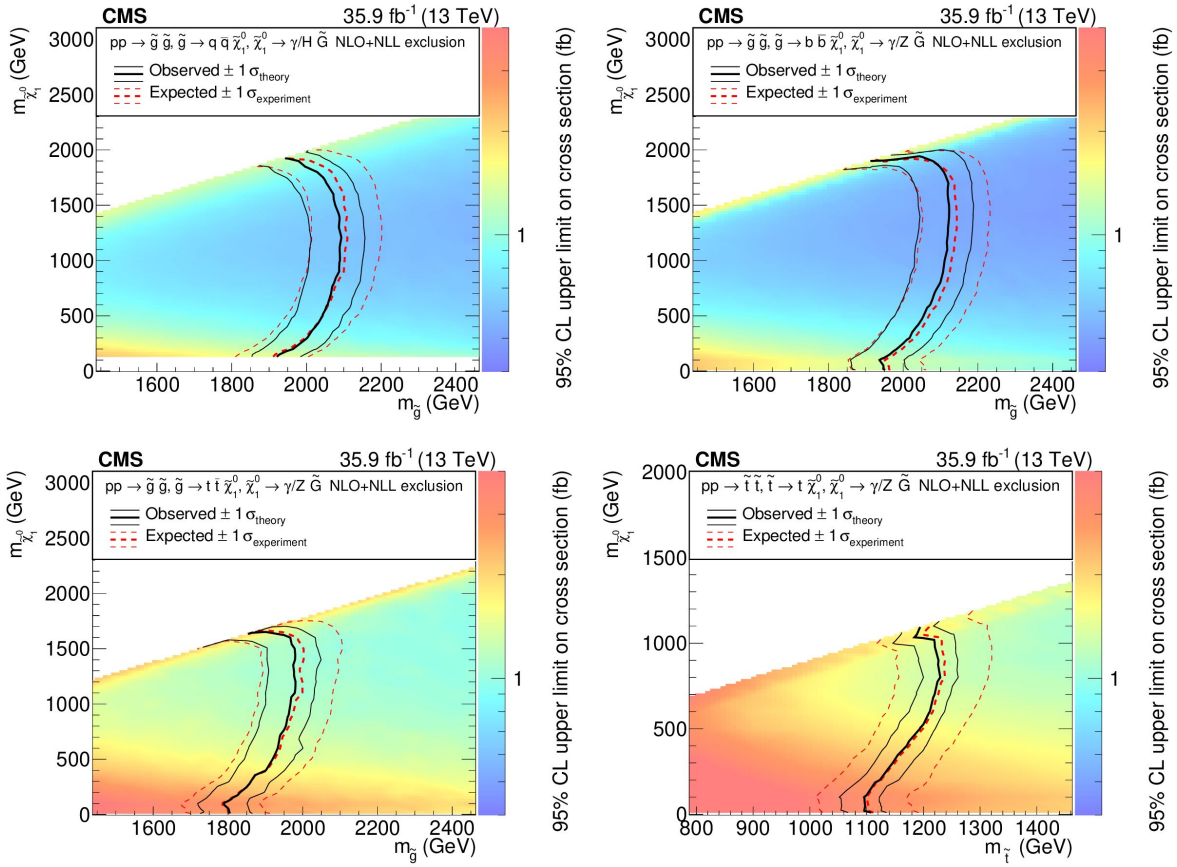
QCD multijet

- $\Delta\phi$jet,MET< 0.3 CR
- MET shape from MC

γ + MET + (b-)jets in strong production SUS-18-002

- Good agreement between expected and observed exclusion
- Limits tend to degrade at extreme as expected due to less jets or less MET in these regions



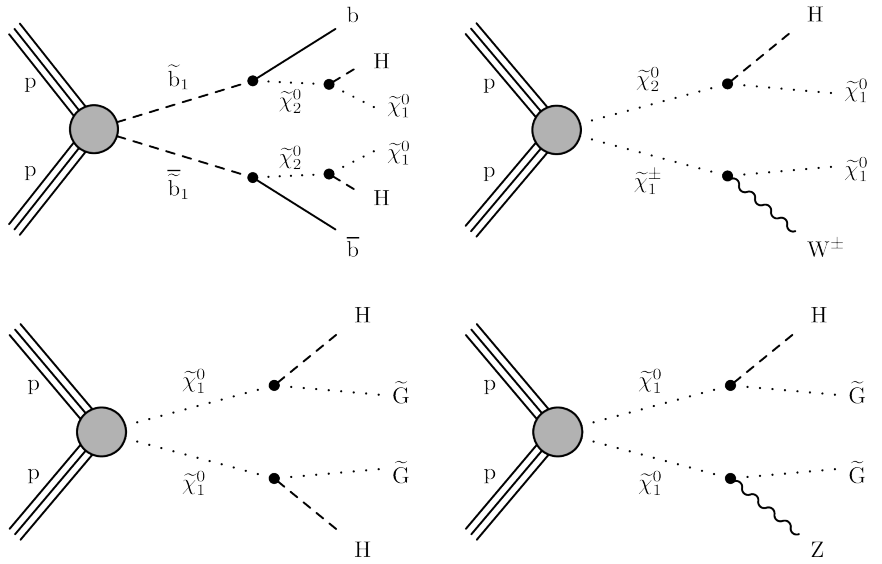


Higgs to $\gamma\gamma$ SUS-18-007

- Framework: GGM
- Process:
  - Squark pair production
  - Chargino-neutralino production
- Data used: 77.5 fb^{-1}

Event selection:

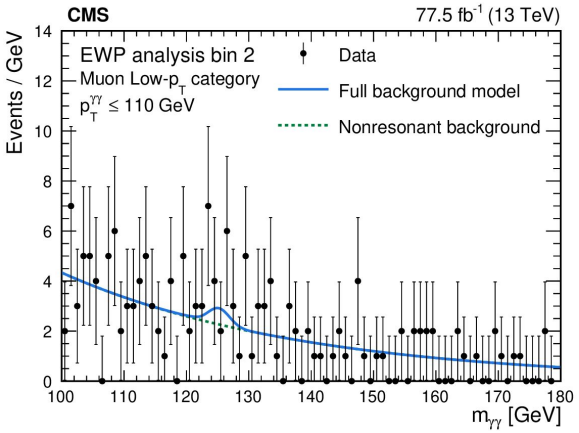
- Photon:
  - $p_T^{\gamma} > 30$ GeV for leading
  - $p_T^{\gamma} > 22$ GeV for subleading
  - $m_{\gamma\gamma} > 100$ GeV

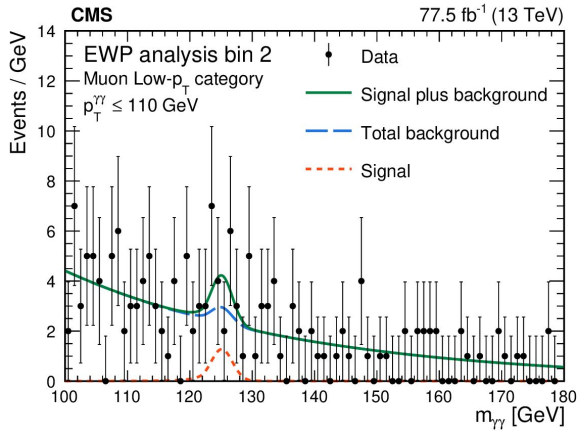


Two complementary strategies:

- Photon pairs in the central region of the detector are used to reconstruct Higgs boson candidates
- Charged leptons and b jets are used to tag the decay products of an additional boson

Higgs to $\gamma\gamma$ SUS-18-007





The diphoton mass distribution shown with the background-only fit (left) and the signal-plus-background fit (right) to illustrate the signal extraction procedure.

Bottom squark mass is 530 GeV for LSP mass of 1 GeV
Chargino masses below 235 GeV