Search for Supersymmetry with photons in CMS at LHC

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Zimányi Winter School, 2017
Budapest

07.12.2017

Introduction and Motivation

What do we mean by SUSY?

- a spacetime symmetry
- relating fermions and bosons
- focus on the Minimal Supersymmetric Standard Model (MSSM)

The problems we see:

- **The nature of dark matter**
- **Hierarchy problem**
- **Grand unification**

Some alternatives: Compact dimensions, Composite Higgs field (Technicolor)

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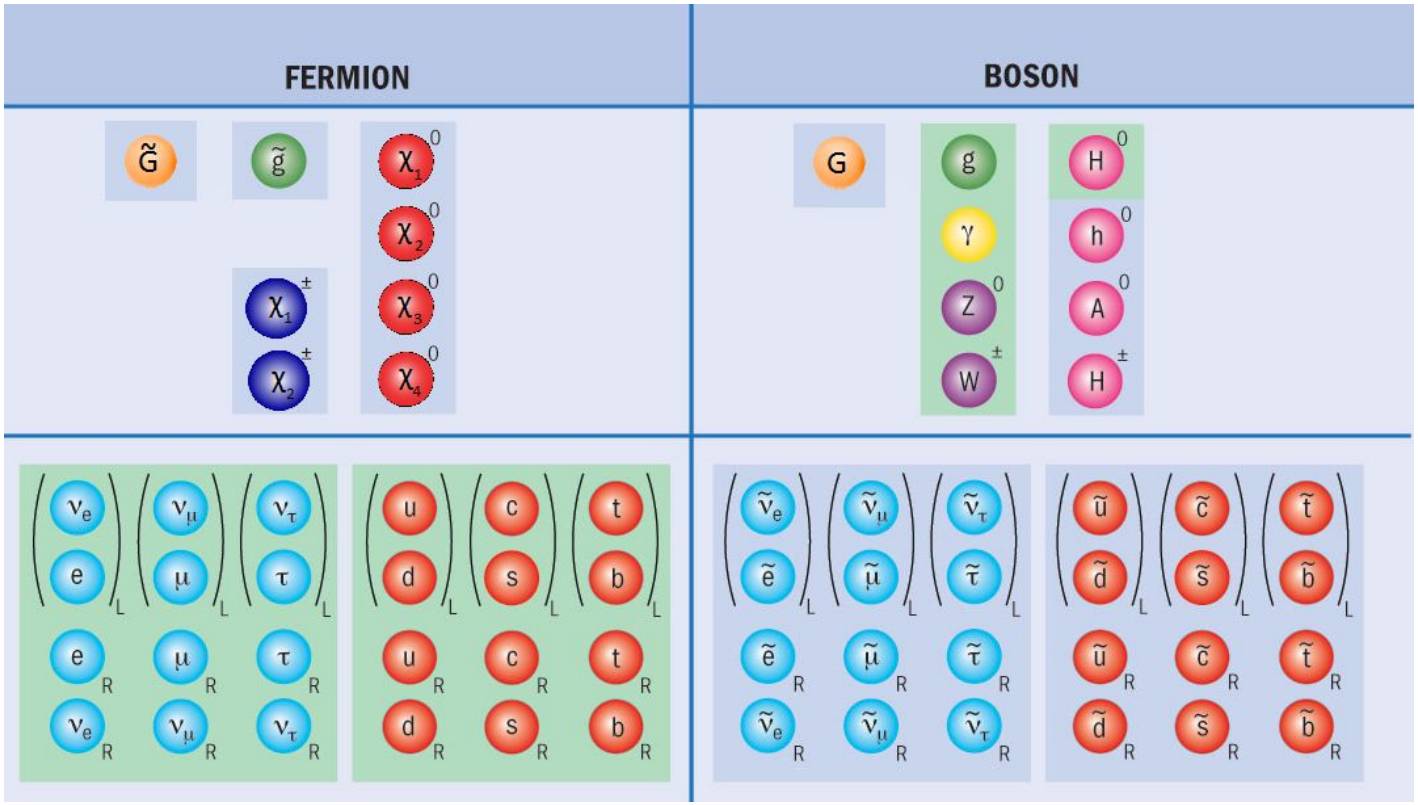
The MSSM Spectrum

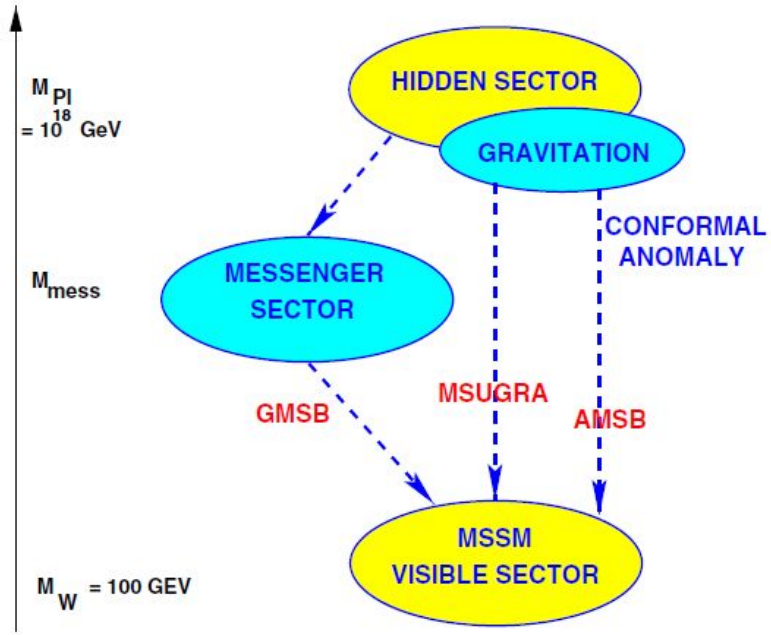
The **MSSM spectrum below the EW scale** (~246 GeV)
Originally 8 degrees of freedom in the Higgs sector → 5 Higgs fields remain
Winos + Binos + Higgsinos → Neutralinos and Charginos



SUSY Breaking

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

- *Sleptons should be easy to see unless the **SUSY is broken***!
- Several symmetry breaking mechanisms proposed
  - Eg: Gauge Mediated Supersymmetry Breaking (GMSB)



R-parity and Lightest SUSY Paricle

R-parity conservation

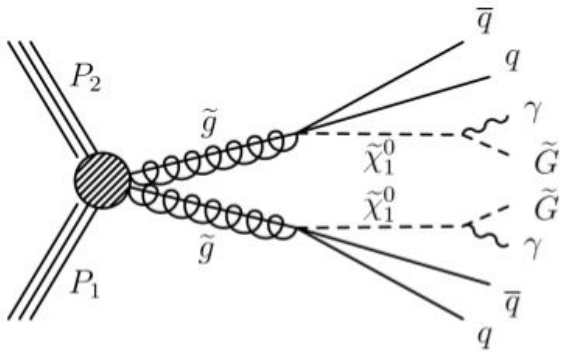
- Baryon number conservation is not hardwired into MSSM
- R-parity is introduced to rule out undesirable couplings:

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

- SUSY particles are produced in pairs
- Lightest supersymmetric particles (LSP) are stable

In MSSM with GMSB and R-parity conservation:

- **LSP** is always the gravitino (WIMP candidate)
- **Next-to-LSP** (NLSP) is a neutralino
- The NLSP decays as: $\tilde{\chi}_1^0 \rightarrow \tilde{G} + \gamma/Z/H$

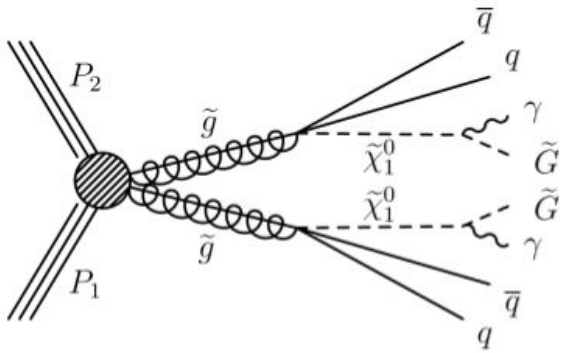


Characterizing SUSY Final States

How to find traces of GMSB MSSM using photons?

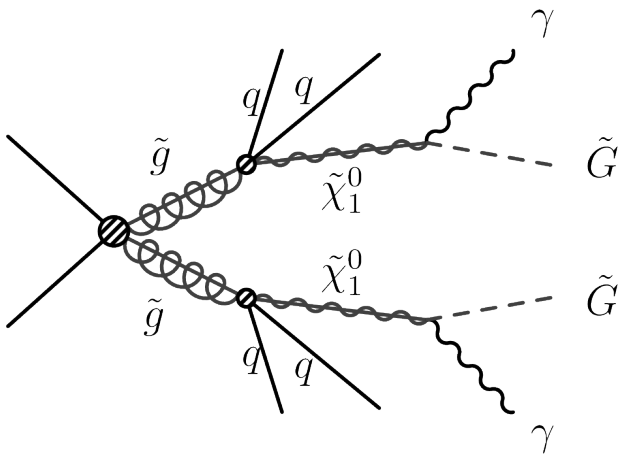
- **Missing Transverse Energy (MET):**
  - Momentum imbalance of all observed physics objects
  - Contributions:
    - MSSM signal: gravitinos
    - SM background: neutrinos, jet momentum mismeasurement
- **Large Hadronic Activity:**
  - Many reconstructed jets
  - $H_T = \sum |p_T(i)|$
- **Reconstructed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

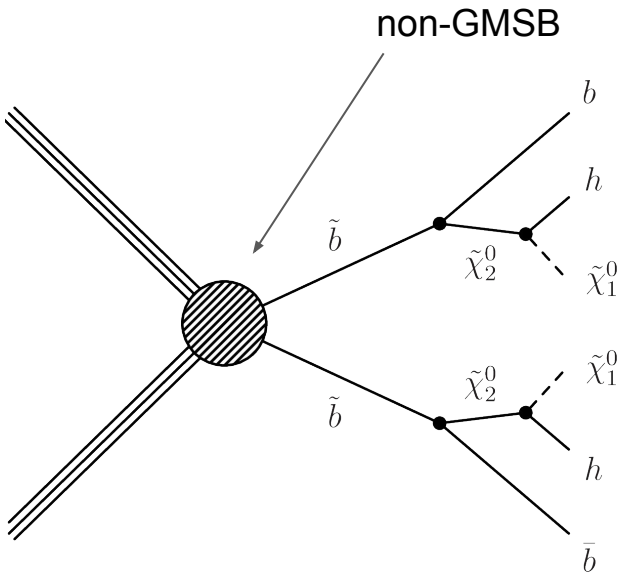
$$M_T^2(\gamma, E_T^{miss}) = 2E_T^{miss} E_T^{\gamma}[1 - \cos\Delta\phi(\vec{p}_T^{miss}, \gamma)]$$

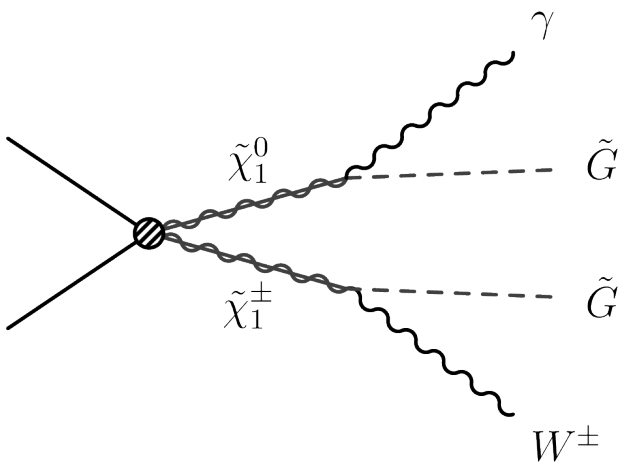


Experimental Results Using Photons at CMS

- According to final state
  - H→$\gamma\gamma$ with Razor
  - γ + MET
  - γ + MET + H_T
- According to tested signal
  - Production:
    - Strong process (squark, gluino)
    - Weak process (chargino or neutralino)
  - Different susy particle decay chains to LSP





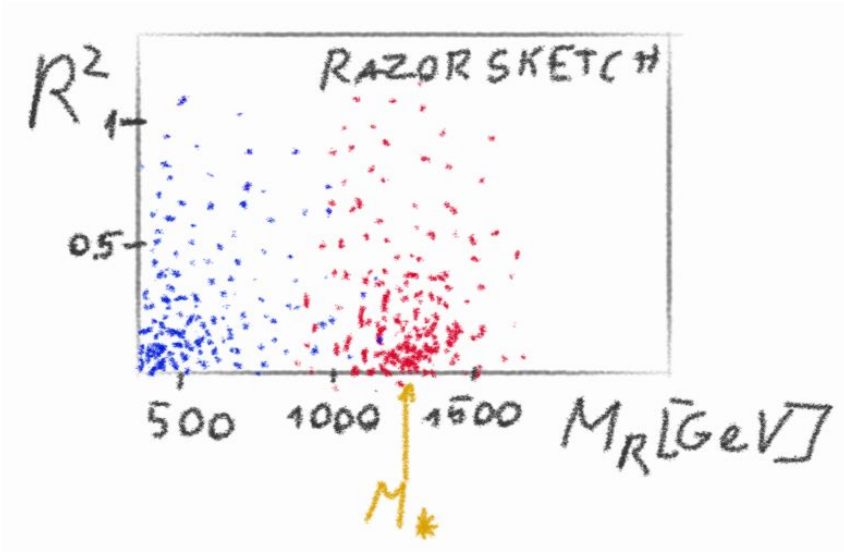


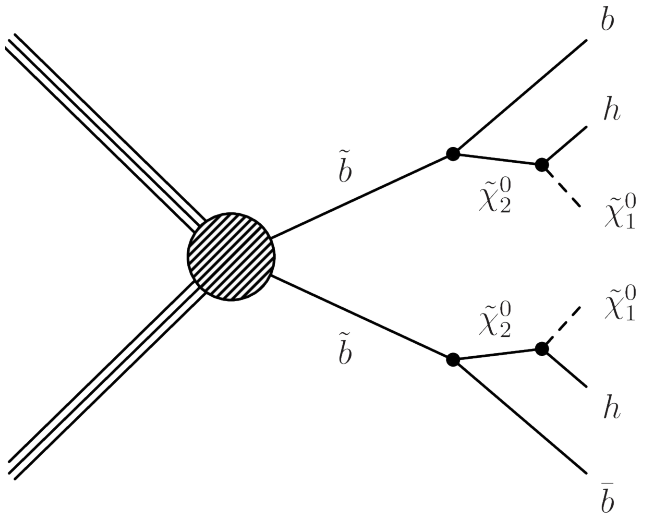
Razor H→$\gamma\gamma$ at 13 TeV (35.9 fb^{-1})

- Results interpreted in a simplified MSSM model (non-GMSB) CMS-SUS-16-045

Event selection:

- Diphoton trigger: $E_T \geq$ 30 GeV, 18 GeV, Invariant mass: 90 GeV
- Leading photon $E_T \geq$ 40 GeV, subleading $E_T \geq$ 20 GeV
- The pair with highest scalar momenta sum → Higgs candidate
- At least one jet $P_T \geq$ 30 GeV
- The MET cut is built into the Razor variables

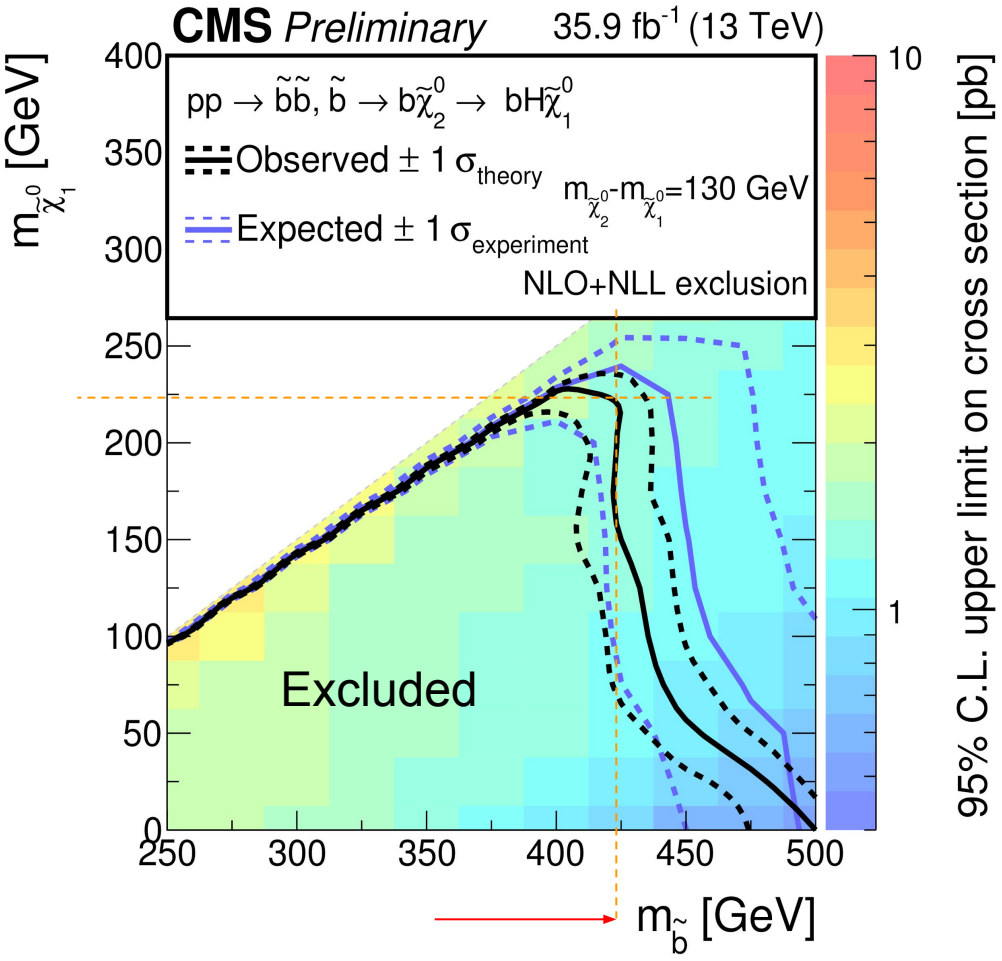




Razor H→$\gamma\gamma$ at 13 TeV (35.9 fb^{-1})

CMS-SUS-16-045

Exclusion plot:



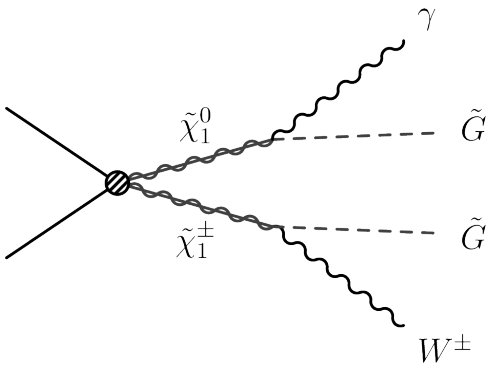
γ + MET at 13 TeV (2.3 and 35.9 fb^{-1})

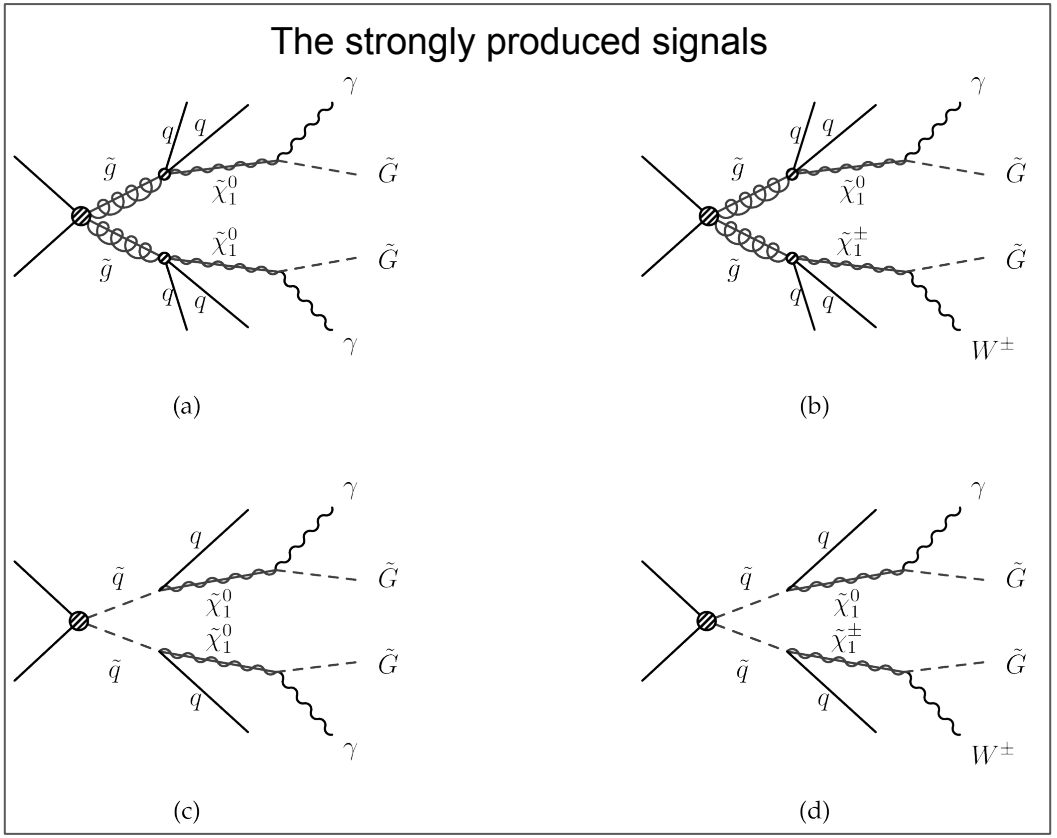
CMS-SUS-16-046

Many different signals considered in multiple search bins

Event selection:

- Single photon trigger 165 GeV
- A loose photon ≥ 180 GeV on the barrel isolated from jets
- MET ≥ 300 GeV
- M_T (γ,MET) ≥ 300 GeV
- S_T gives the bins



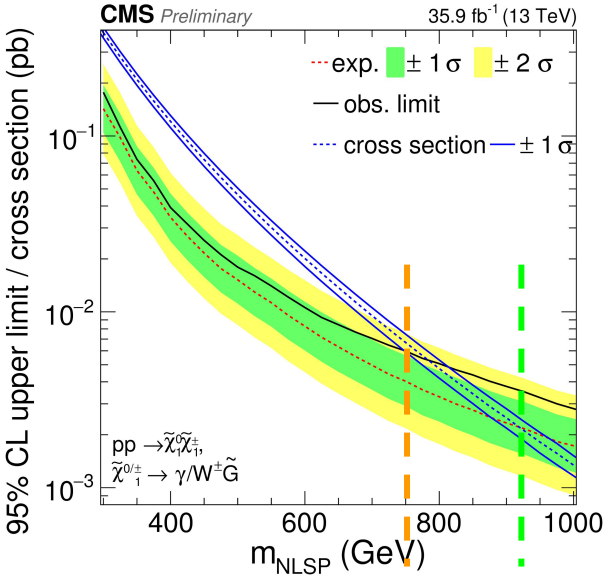


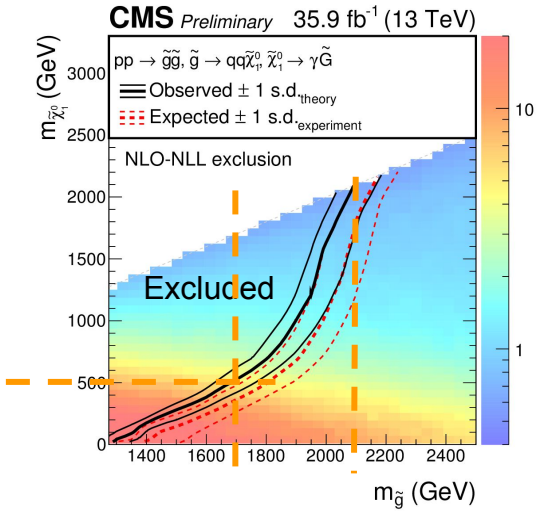
γ + MET at 13 TeV (35.9 fb^{-1})

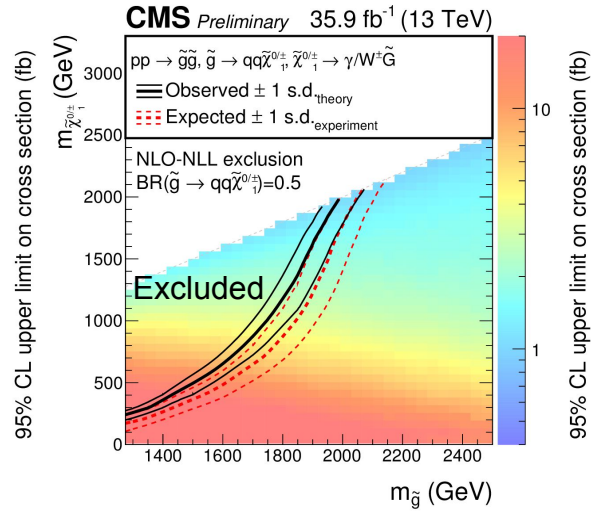
CMS-SUS-16-046

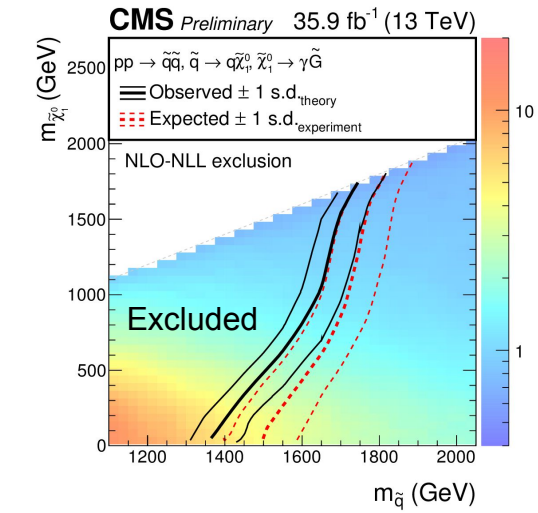
Weak case: m_{NLSP}<750 GeV, an improvement of ~150 GeV

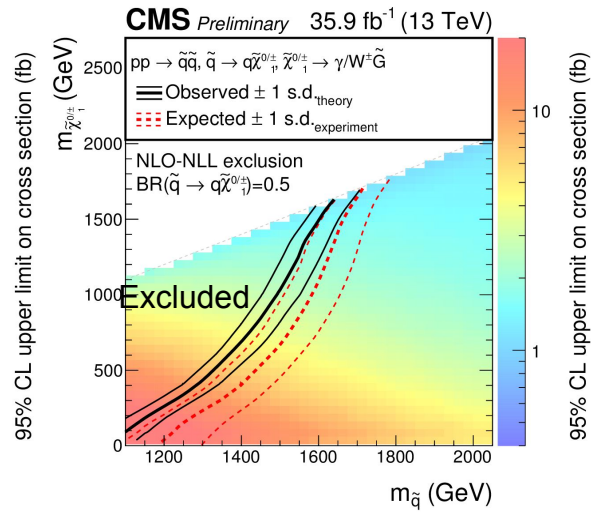
Diagonal exclusions improved in the strong channels
1740 GeV→ 2100 GeV for gluino
1300 GeV→ 1650 GeV for squark











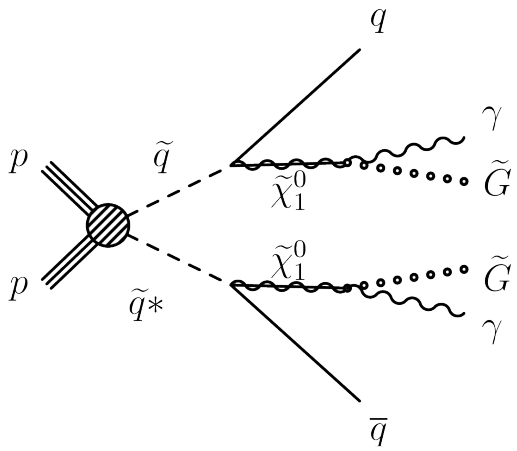
γ + MET + H_T at 13 TeV (35.9 fb^{-1})

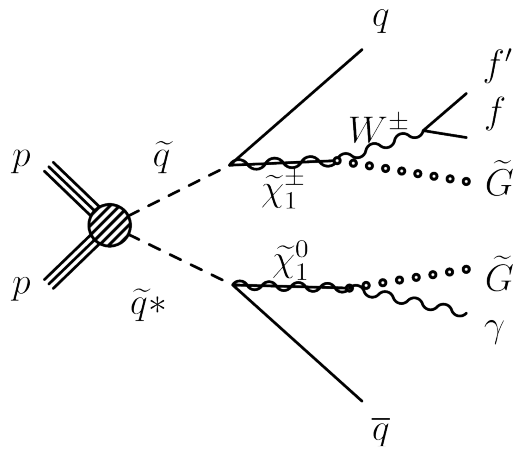
CMS-SUS-16-047

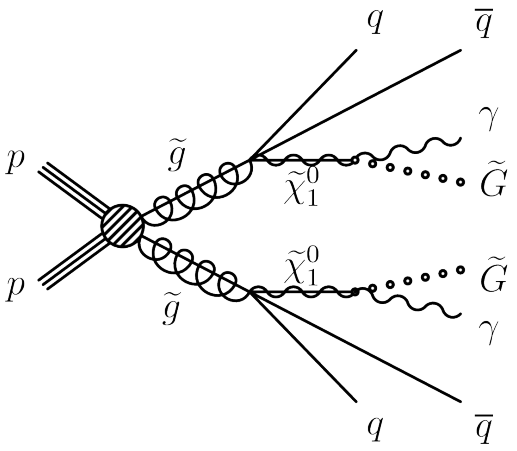
Strong production channels

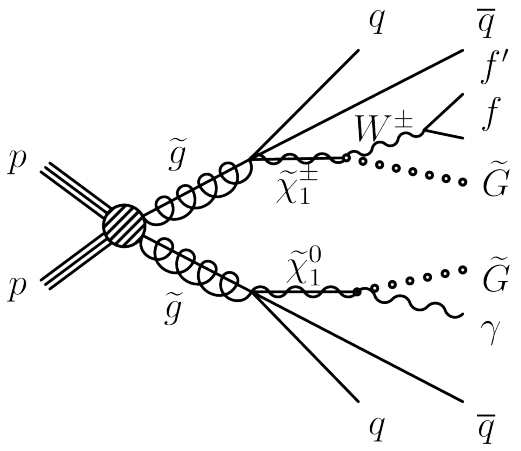
Event selection:

- $H_T \geq 600$ GeV trigger
- A photon ≥ 100 GeV
- Search bins are defined using MET and S_T





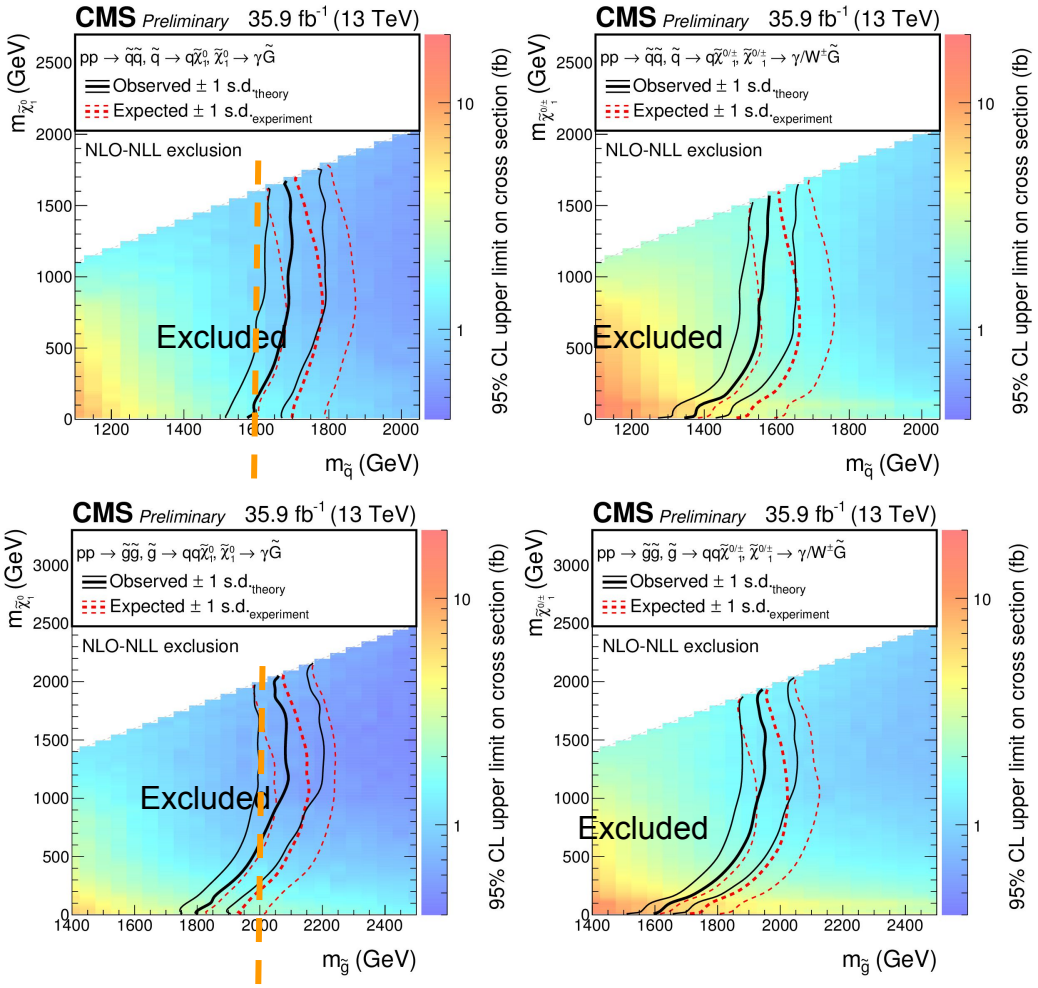




γ + MET + H_T at 13 TeV (35.9 fb^{-1})

CMS-SUS-16-047

Gluino masses up to 2 TeV and
squark masses up to 1.6 TeV are excluded (previously 1.6 and 1.35 using 2.3 fb^{-1})



Summary

- Searches address a large area of the GMSB MSSM parameter space
- Photon and Higgs boson decay channels are popular
- If 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 ~3% of the full pp integrated luminosity recorded yet

  The adventure is just starting...

Backup - Razor variables

- Cluster all PF object in two hemispheres using the "*megajet*" algorithm
- The variables are computed as

$$M_{\mathrm{T}}^{\mathrm{R}} \equiv \sqrt{\frac{E_{\mathrm{T}}^{\mathrm{miss}}(p_{\mathrm{T}}^{j_1}+p_{\mathrm{T}}^{j_2}) - \vec{p}_{\mathrm{T}}^{\mathrm{miss}}\cdot(\vec{p}_{\mathrm{T}}^{j_1}+\vec{p}_{\mathrm{T}}^{j_2})}{2}}$$

$$M_{\mathrm{R}} \equiv \sqrt{(|\vec{p}^{j_1}|+|\vec{p}^{j_2}|)^2-(p_z^{j_1}+p_z^{j_2})^2}$$

$$\mathrm{R}^2 \equiv \left(\frac{M_{\mathrm{T}}^{\mathrm{R}}}{M_{\mathrm{R}}}\right)^2$$

- These show exponential decay for SM Higgs production, but have large values for MSSM production

Backup - Razor variables II