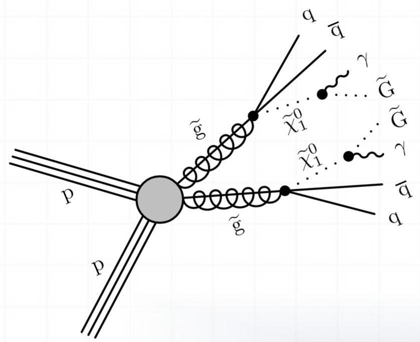
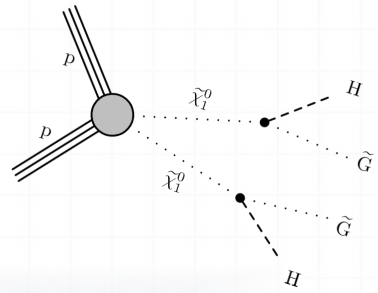




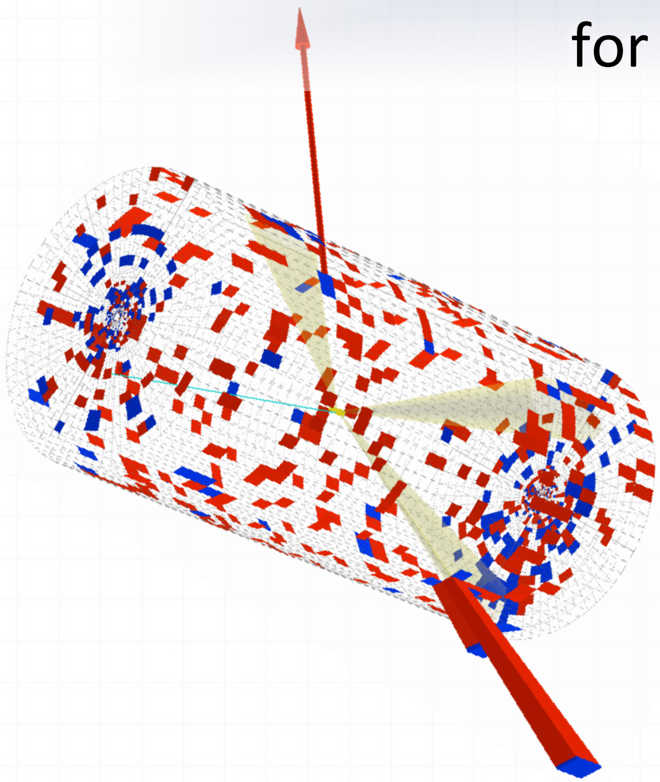
Search for supersymmetry with GMSB

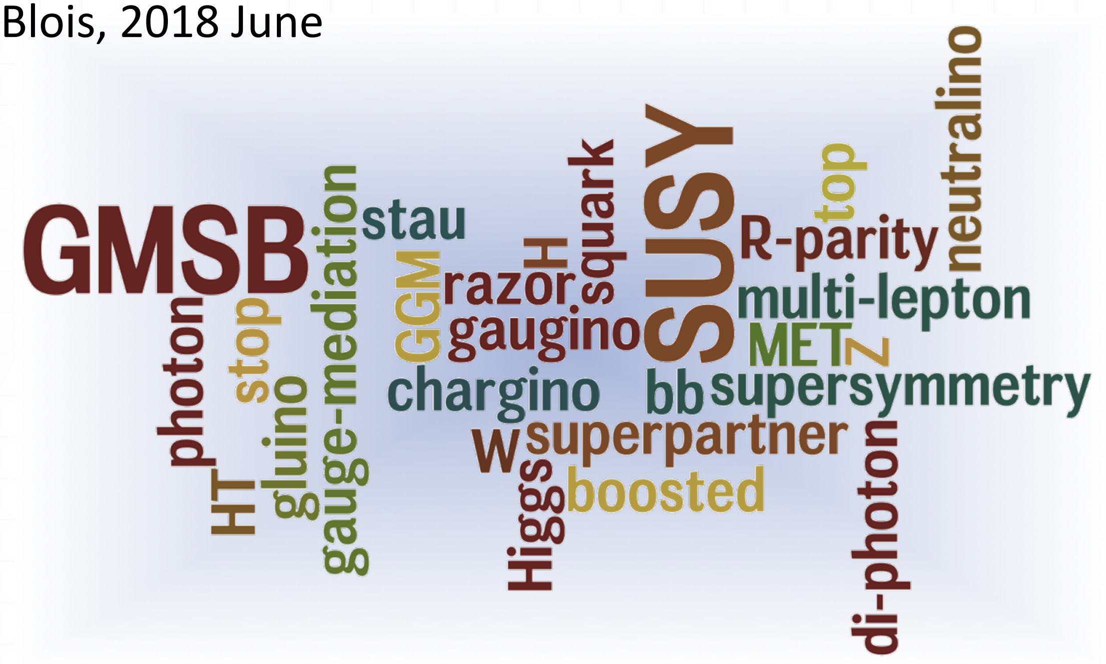
Gabriella Pásztor

(MTA-ELTE, Eötvös University, Budapest)

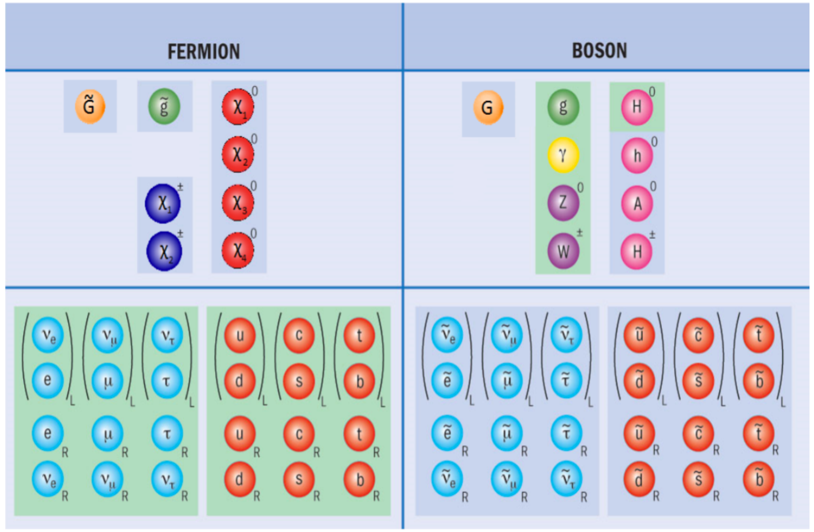
for the CMS Collaborations

Blois, 2018 June





Supersymmetry (SUSY)



- **Symmetry between fermionic and bosonic states**
  - Only non-trivial extension of Poincare algebra
  - “Predicted” by string theory
- **Superpartners with spin differing by ½**
  - No sparticle discovered at low mass
    → **SUSY broken**
- Solutions to SM problems
  - LSP: dark matter candidate
  - Sparticles can cancel large quantum corrections to m_H
  - … help gauge coupling unification
- SUSY breaking mechanism not known → >100 new parameters
- Several (benchmark) models with <10 parameters:
  Minimal Supergravity, **Gauge Mediated SUSY Breaking (GMSB)**, …
- **Simplified models** = bridge between theory and experiment
  - Only small number of new particles and interactions → easy to simulate
    - Particle masses, production cross-sections, branching factions
  - Derive quasi-model-independent cross-section * branching ratio limits
    - Applicable in models predicting the same final state

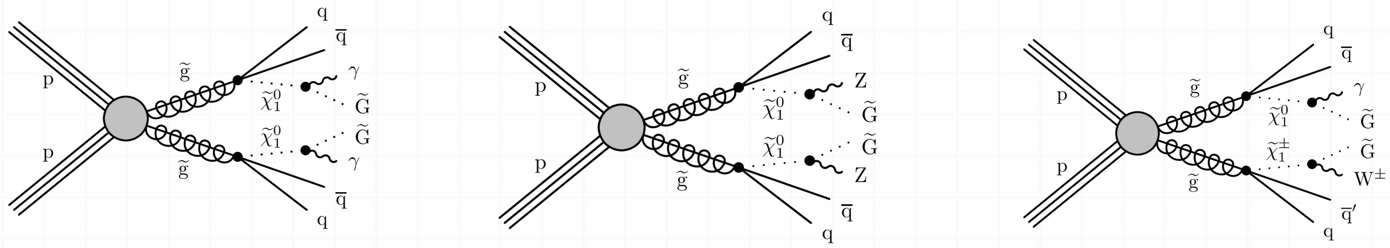
Signatures from Gauge Mediated SUSY Breaking

- **SUSY breaking mediated from hidden to visible sector by gauge interactions**

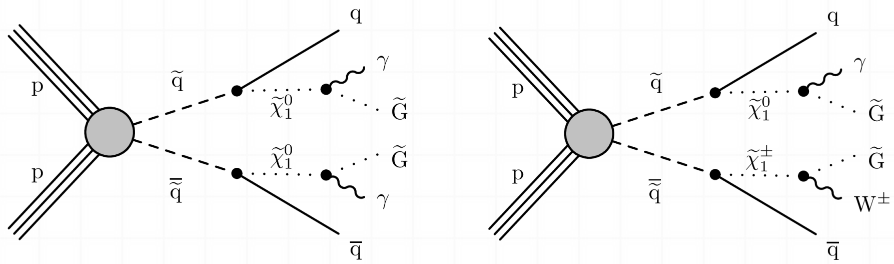
- **Lightest SUSY particle (LSP): gravitino**, $\tilde{G}$
  - Weakly interacting, neutral
  - Taken to be nearly massless
- Assuming R-parity conserved → SUSY particles produced in pairs
  → decay (via a cascade) to a stable gravitino LSP
  → experimental signature: missing transverse momentum
- **Next-to-lightest SUSY particle** (NLSP) typically
  - Neutralino, $\tilde{\chi}_1^0$
    - Decays to γ/Z/H + $\tilde{G}$
    - If mass-degenerate with wino-like chargino, $\tilde{\chi}_1^{\pm}$ → $W^{\pm}\tilde{G}$ possible
    - Final states including photons, leptons from W/Z decays, bb, $\gamma\gamma$ from Higgs decays
  - Scalar tau, $\tilde{\tau}$
    - Can be long-lived

Strong production (examples)

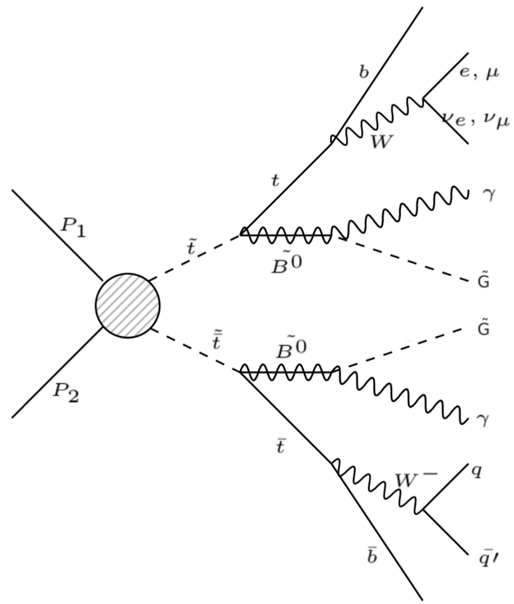
Gluino production



Squark production



Stop production



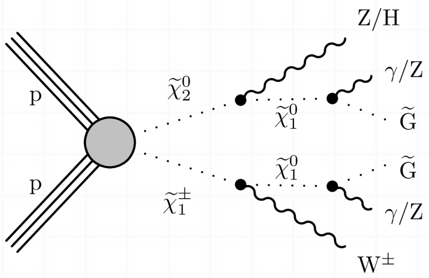
- Missing transverse energy
- Large hadronic activity (if Δm not too small)
- Photon(s) and/or
- Lepton(s) from W, Z, H decays

Gaugino production (examples)

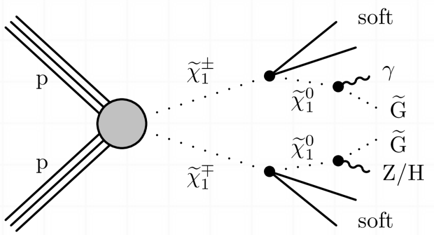
Lower cross-section than strong production
Important if gluinos, quarks inaccessible

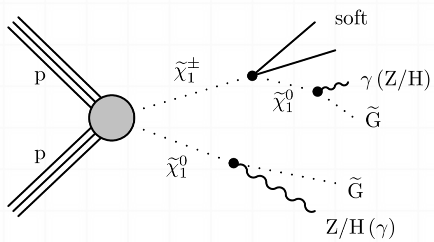
- Missing transverse energy
- Photon(s) and/or
- Leptons from W, Z, H decays and/or
- H→bb, $\gamma\gamma$

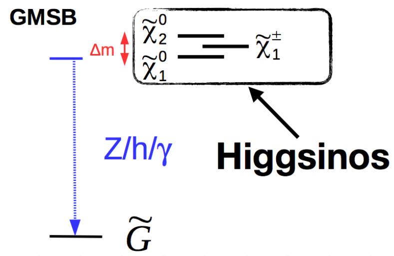
Cascade



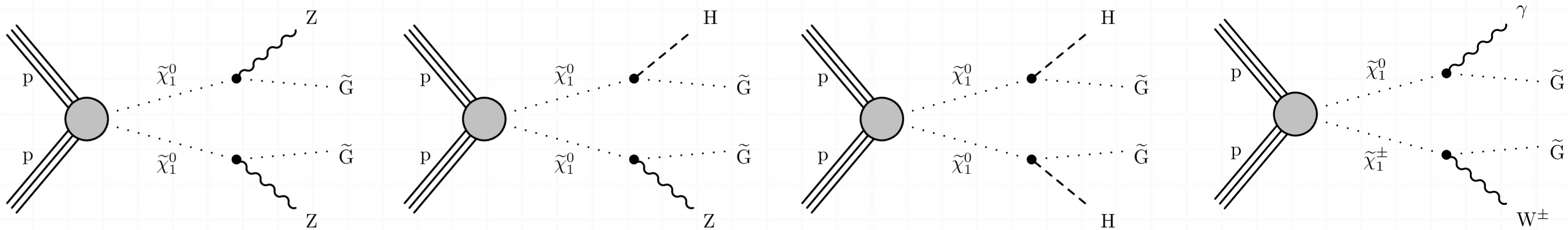
Cascade with mall mass difference (undetected particles from $W^{\pm *}$)







Mass-degenerate scenarios



Recent CMS GMSB results

- Photon + MET, PLB 780 (2018) 118
- Photon + MET + large hadronic activity, JHEP 12 (2017) 142
- (Photons + top quark pairs @ 8 TeV, JHEP 03 (2018) 167)

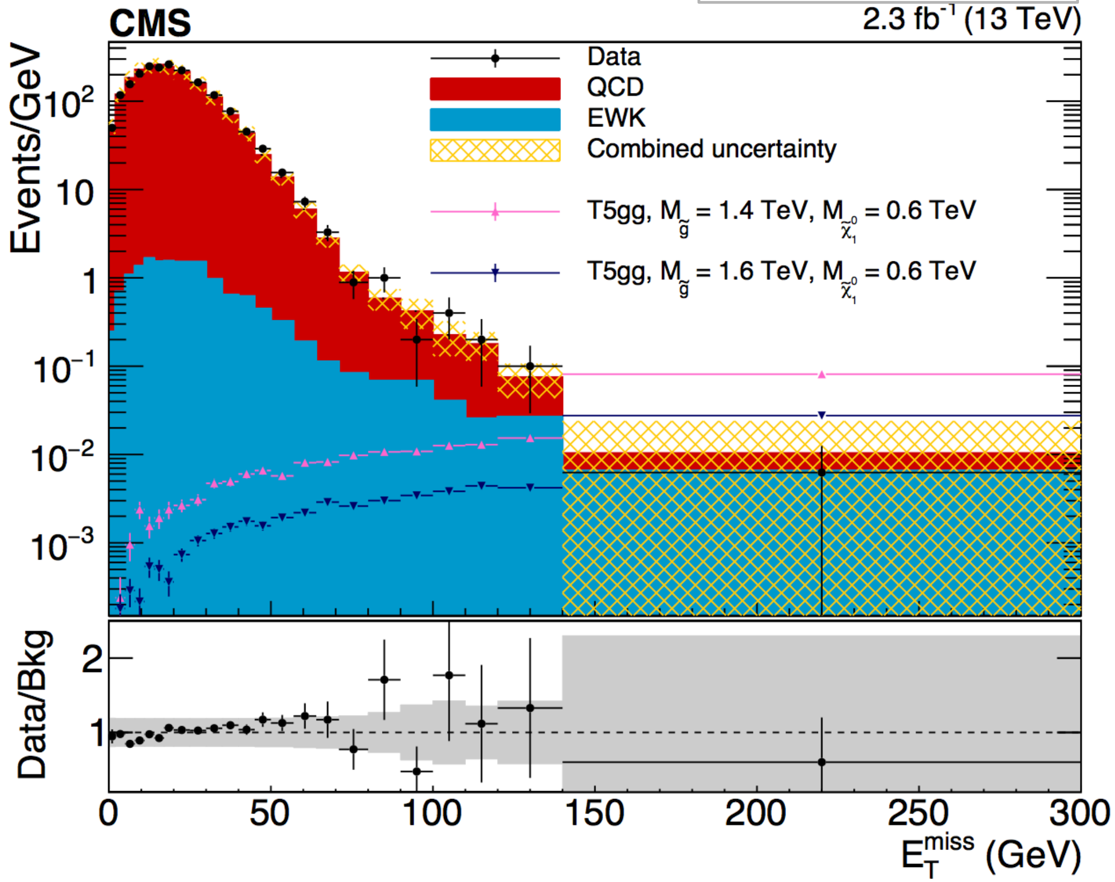
- EW combination, JHEP 03 (2018) 160
  - H → $\gamma\gamma$ + MET, PLB 779 (2018) 166
  - (Opposite-sign same-flavour lepton pair + MET + jets, JHEP 03 (2018) 076)
  - (Three or more leptons, JHEP 03 (2018) 166)
  - HH→bbbb + MET, PRD 97 (2018) 032007

- Long-lived scalar tau, PRD (2017) 112004, CMS-PAS-EXO-16-036

Variables

- Missing E_T (MET): $E_T^{miss} = |\vec{p}_T^{miss}| = |-\sum_i \vec{p}_T(i)|$, i =all objects
  - Important signal of LSP
- Transverse mass (M_T): $M_T^2(\gamma, p_T^{miss}) = 2p_T^{miss} E_T^{\gamma}[1 - \cos\Delta\phi(\vec{p}_T^{miss}, \gamma)]$
  - $M_T \approx m_{NLSP}$, when $\tilde{\chi}_1^0 \to \gamma\tilde{G}$
  - Reduce process $W \to e\nu$ (e misindentified as γ)
- $S_T^{\gamma} = p_T^{miss} + \sum_i E_T^{\gamma_i}$
- $H_T^{\gamma} = \sum p_T^{jets} + \sum_i E_T^{\gamma_i}$

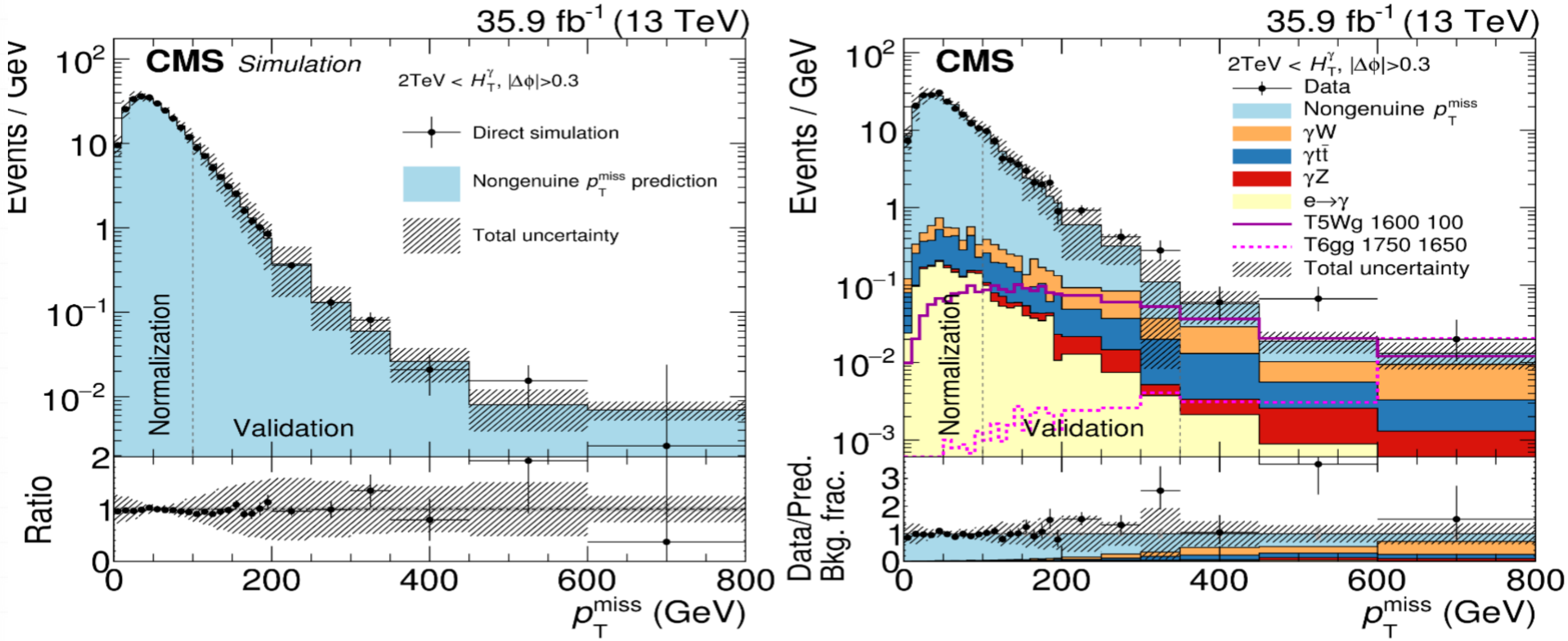
PLB 769 (2017) 391



Photon + MET + large hadronic activity (HT)

- Targets strong gluino- and squark-pair production [≧1 γ + jets]
- Dominant background: γ+jets, e→γ fake
- Data-driven background prediction
  - Estimate from zero-photon CR normalized by low p_T^{miss} CR
  - e→γ fake rate from Z(eγ)/Z(ee) tag-and-probe
- Bin in p_T^{miss} and H_T^γ

$N_\gamma \geq 1,\ E_T^\gamma > 100$ GeV
$|\eta| < 1.44$
$p_T^{miss} > 300$ GeV
$\Delta\phi(\pm\vec{p}_T^{miss}, \vec{p}_T^\gamma) > 0.3$
$H_T^\gamma > 700$ GeV

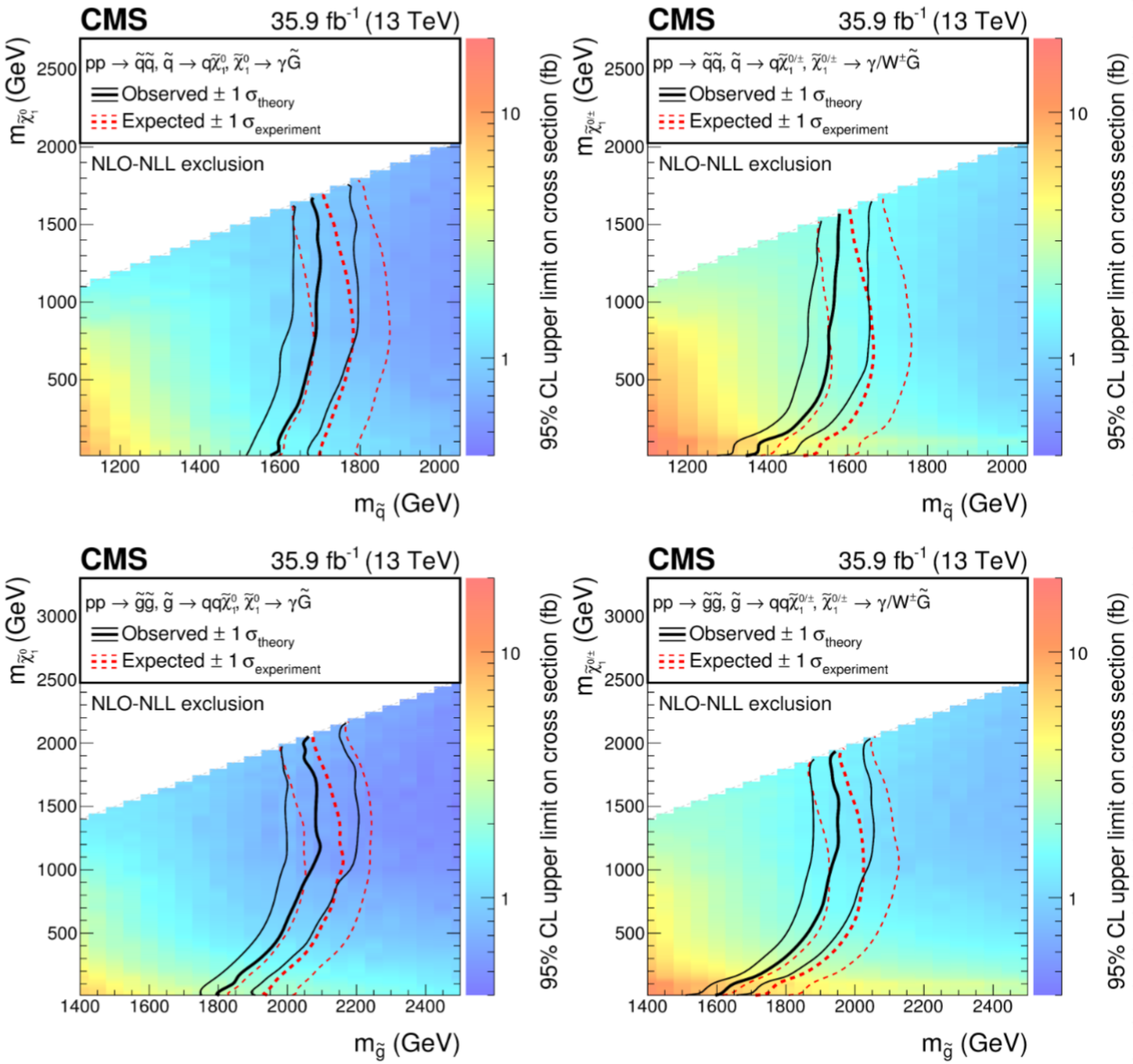


JHEP 12 (2017) 142

Photon + MET + HT results

Interpreted in the context of 4 simplified models

- $\tilde{q} \rightarrow q\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$
  $m_{\tilde{q}} > 1650$ GeV
- $\tilde{q} \rightarrow q\tilde{\chi}_1^0/\tilde{\chi}_1^\pm \rightarrow \gamma/W^\pm\tilde{G}$
  $m_{\tilde{q}} > 1550$ GeV
- $\tilde{g} \rightarrow qq\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$
  $m_{\tilde{g}} > 2000$ GeV
- $\tilde{g} \rightarrow qq\tilde{\chi}_1^0/\tilde{\chi}_1^\pm \rightarrow \gamma/W^\pm\tilde{G}$
  $m_{\tilde{g}} > 1900$ GeV

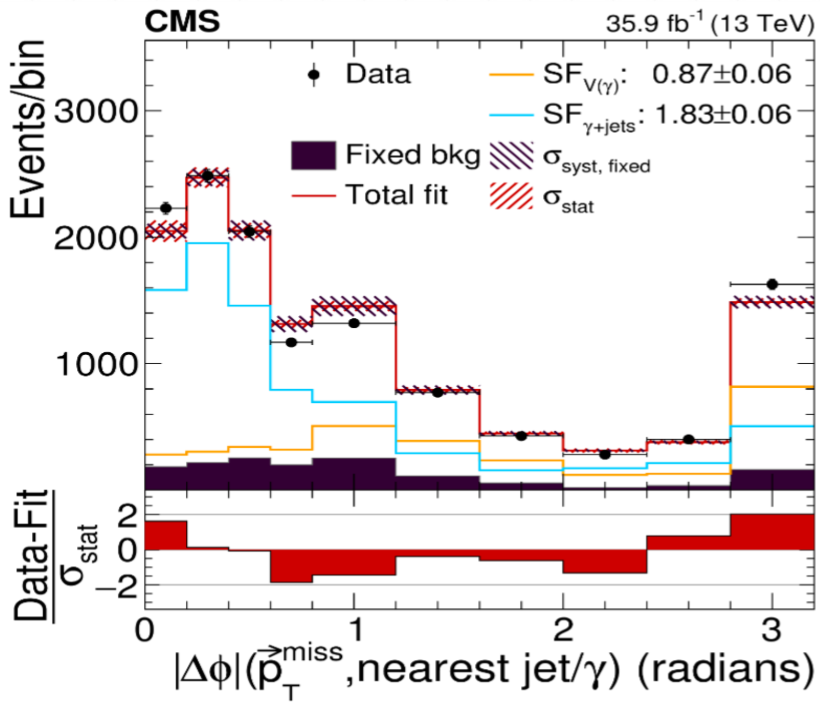


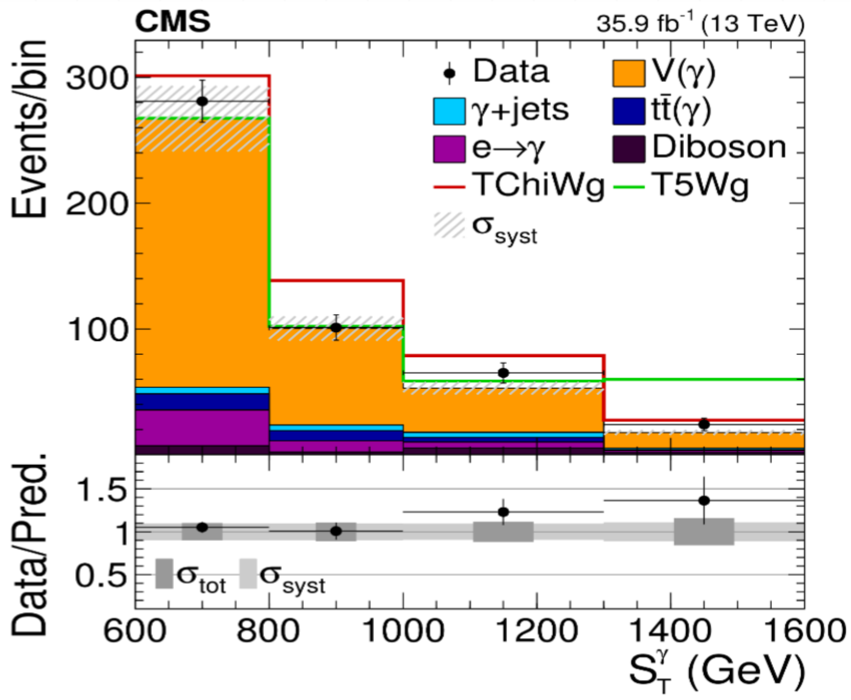
PLB 780 (2018) 118

Photon + MET

- Targets EW processes and strong production with small mass difference [≧1 γ (+ jets)]
- Dominant background: V(γ)+jets, γ+jets, e→γ fake
- Semi data-driven background estimation
  - Derive scale factor from fit of MC to data in low p_T^{miss} and/or M_T CR
  - e→γ fake rate from Z(eγ)/Z(ee) tag-and-probe
- Binned in S_T^{γ}

$$N_\gamma \geq 1,\ E_T^\gamma > 180\ \text{GeV},\ |\eta| < 1.44$$
$$p_T^{miss} > 300\ \text{GeV}$$
$$M_T(\gamma, \vec{p}_T^{miss}) > 300\ \text{GeV}$$
$$\Delta\phi(\vec{p}_T^{miss}, \vec{p}_T^{jet}) > 0.3 \text{ if } p_T^{jet} > 100\ \text{GeV}$$
$$S_T^\gamma > 600\ \text{GeV}$$

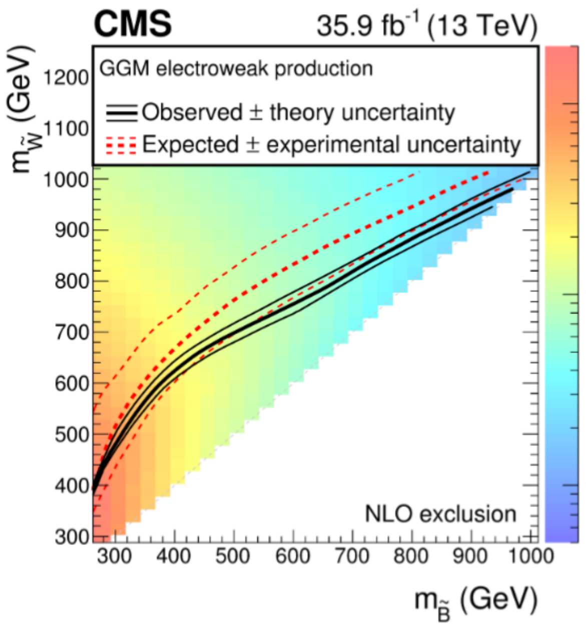




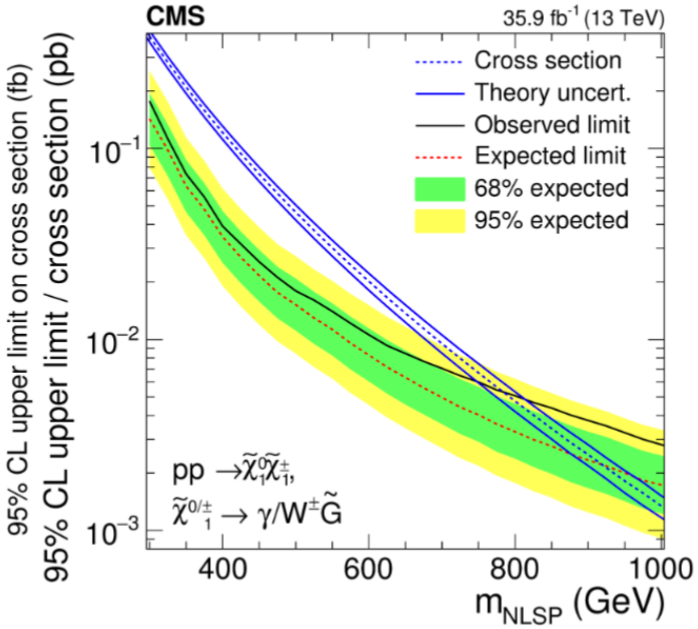
PLB 780 (2018) 118

Photon + MET results

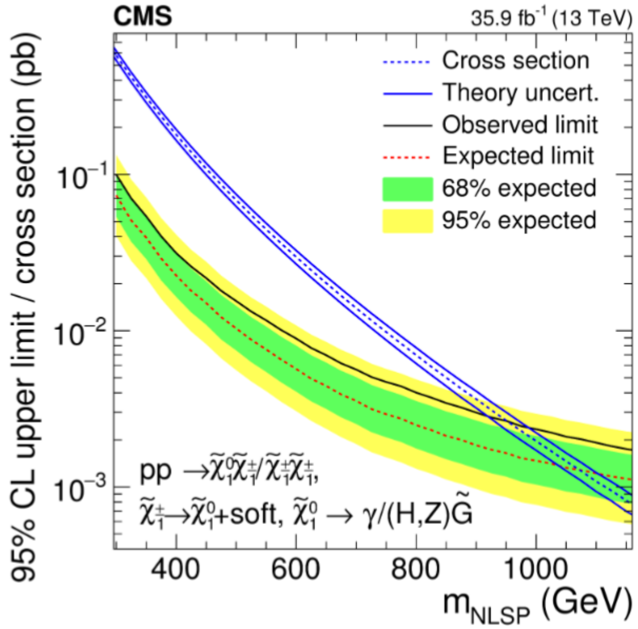
- $m_{\tilde{B}} \approx m_{\tilde{W}} > 900$ GeV GGM interpretation



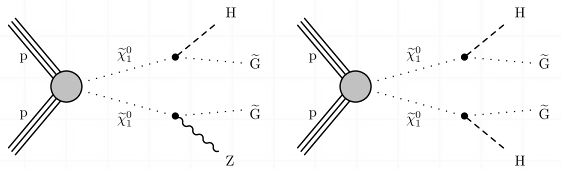
- $\tilde{\chi}_1^0 \tilde{\chi}_1^\pm \to \gamma W^\pm \tilde{G}$ $m_{NLSP} > 780$ GeV



- $\tilde{\chi}_1^0 \tilde{\chi}_1^\pm \to \gamma / H / Z \tilde{G}$ $m_{NLSP} > 950$ GeV



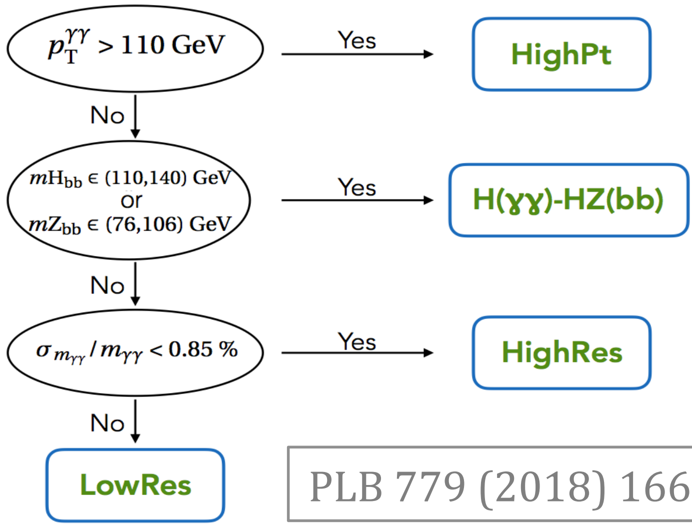
0 For strong production improves limits for low gluino/squark – neutralino mass difference wrt previous "Photon + MET + HT" search



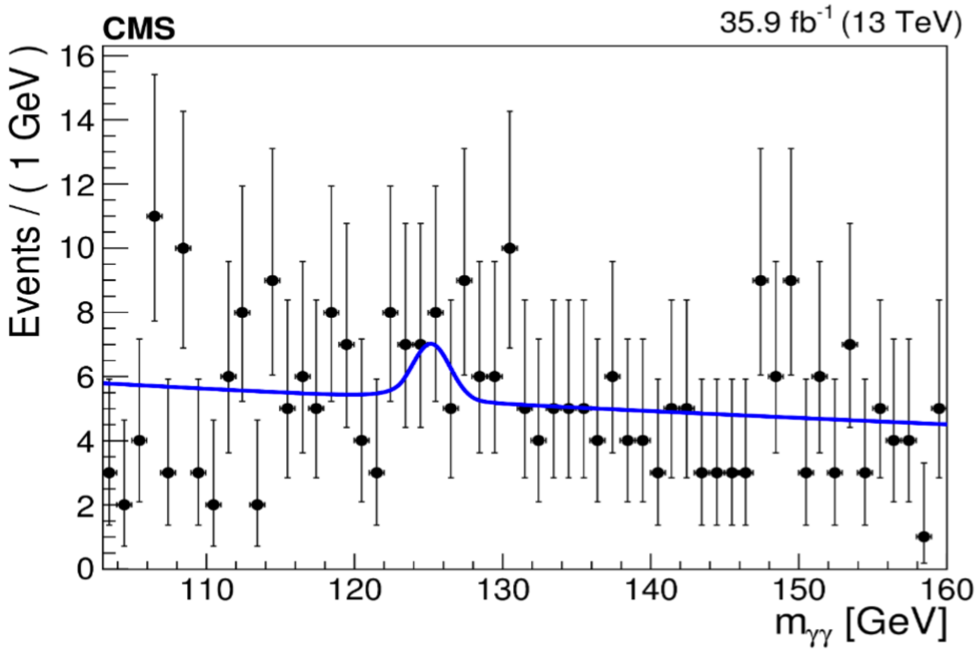
H→γγ + MET

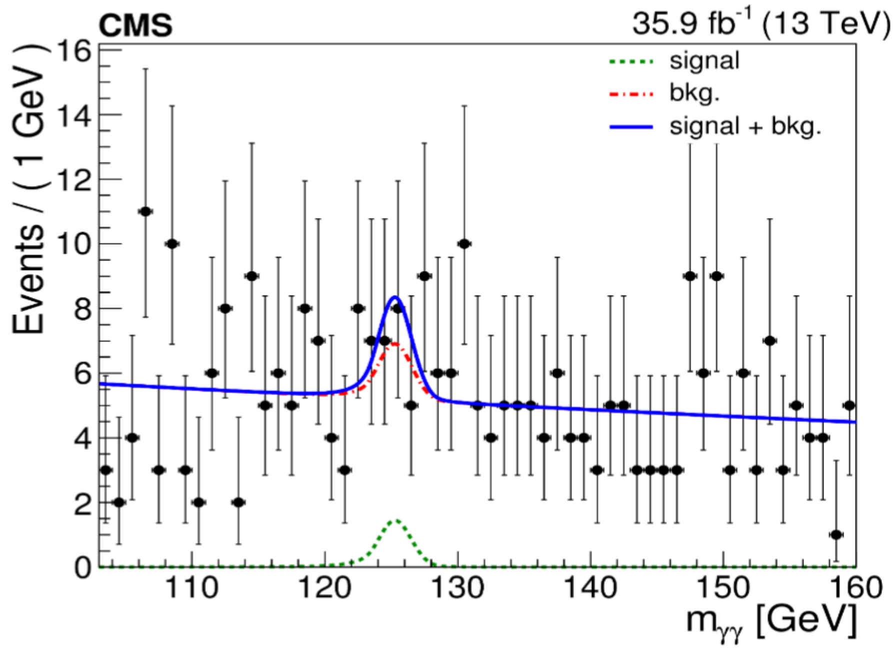
$N_\gamma \geq 2,\ m_{\gamma\gamma} \approx 125$ GeV
$|\eta| < 1.44$
$M_R > 150$ GeV

- Targets EW production with 1 or 2 Higgs in the final state
- Dominant background $\gamma\gamma$+jets, γ+jets, SM Higgs
- Background prediction:
  - QCD: fit $m_{\gamma\gamma}$ spectrum
  - SM Higgs: MC prediction
- Binning in M_R, R^2 in 4 categories: High P_T, $H(\gamma\gamma)$ – HZ(bb), high resolution, low resolution



PLB 779 (2018) 166





Razor variables

- Based on pair production of two heavy particles
- Decaying to undetected particle + visible products
- All events treated like di-jet event
- Reconstructed objects → two megajets j_1, j_2

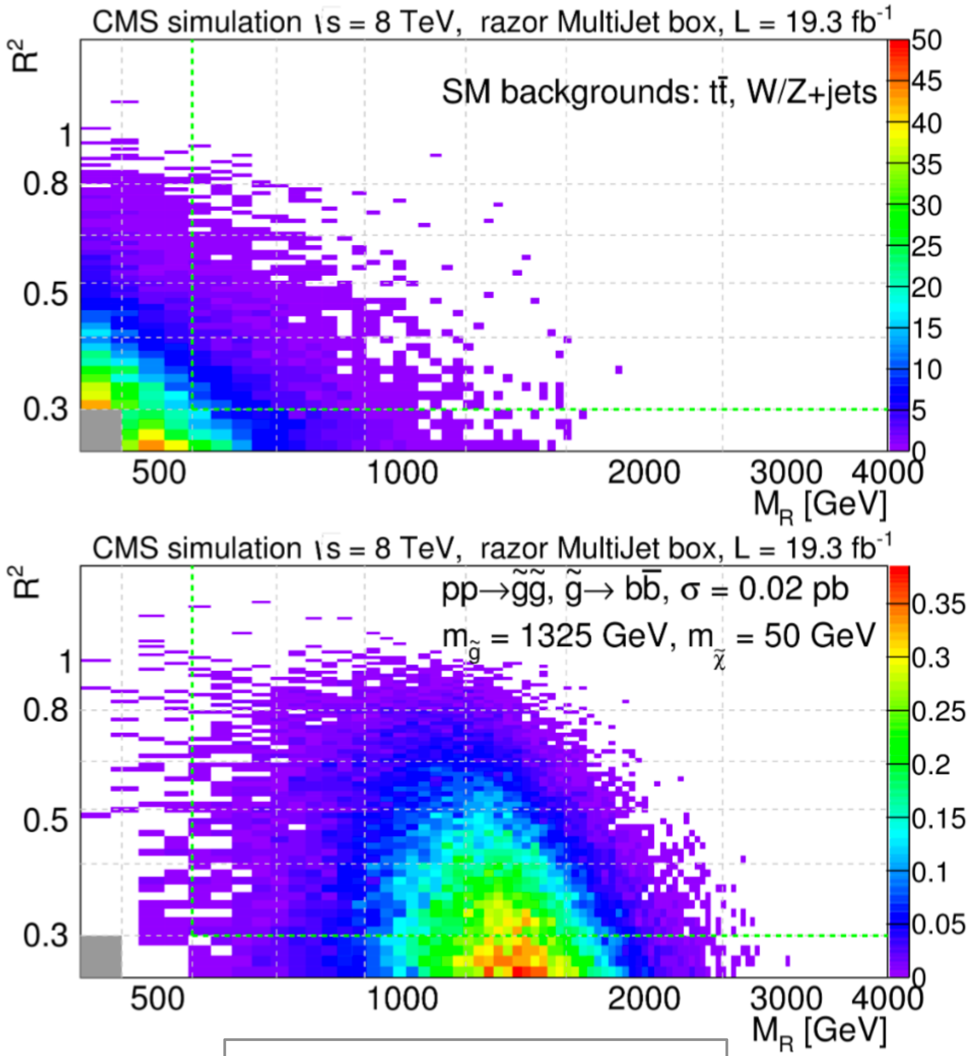
$$M_R = \sqrt{(|\vec{p}^{j_1}| + |\vec{p}^{j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_R \approx \frac{m_{\tilde{X}}^2 - m_{LSP}^2}{2m_{\tilde{X}}}$$

$$M_T^R = \sqrt{\frac{p_T^{miss}(p_T^{j_1} + p_T^{j_2}) - \vec{p}_T^{miss}(\vec{p}_T^{j_1} + \vec{p}_T^{j_2})}{2}}$$

$$R^2 = (\frac{M_T^R}{M_R})^2$$

- SM background exponentially falling
- SUSY signals large values of M_R, R^2



PRD 91 (2015) 052018

PLB 779 (2018) 166

H→$\gamma\gamma$ + MET results

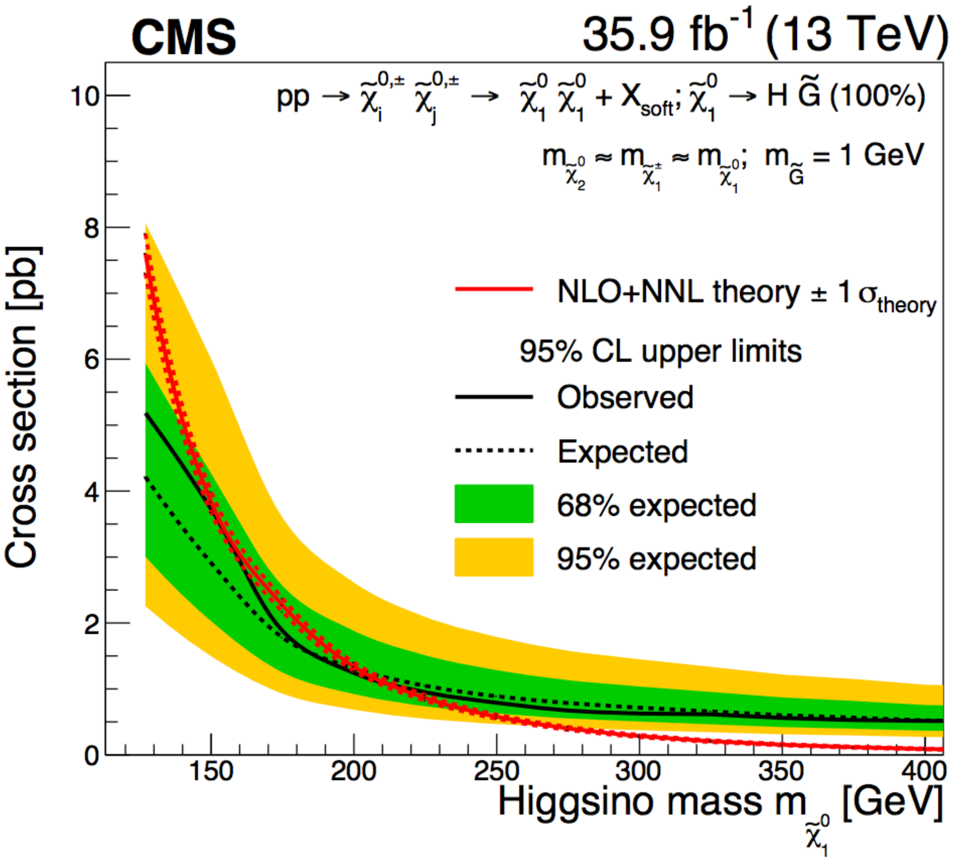
Interpreted in the context of simplified models

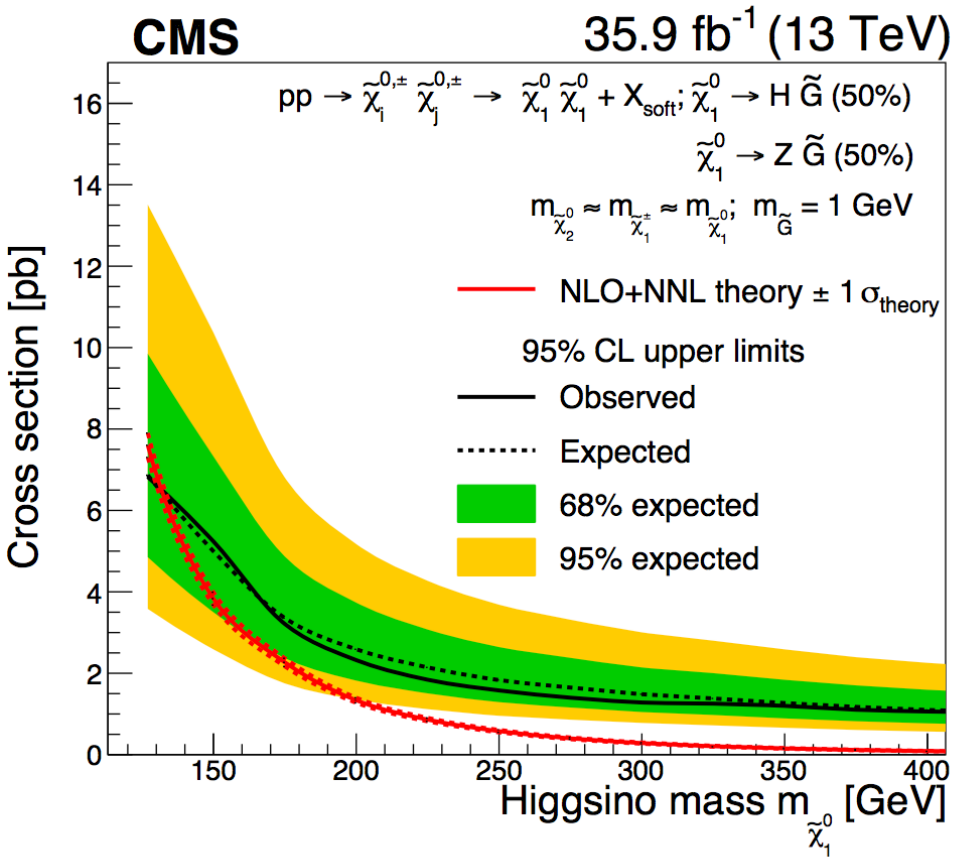
$\tilde{\chi}_1^0 \rightarrow H\tilde{G}$

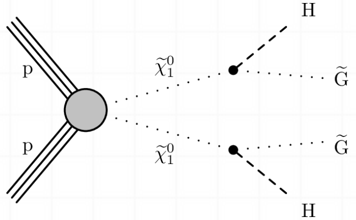
$m_{\tilde{\chi}_1^0} > 205$ GeV

$\tilde{\chi}_1^0 \rightarrow H/Z\tilde{G}$

$m_{\tilde{\chi}_1^0} > 130$ GeV





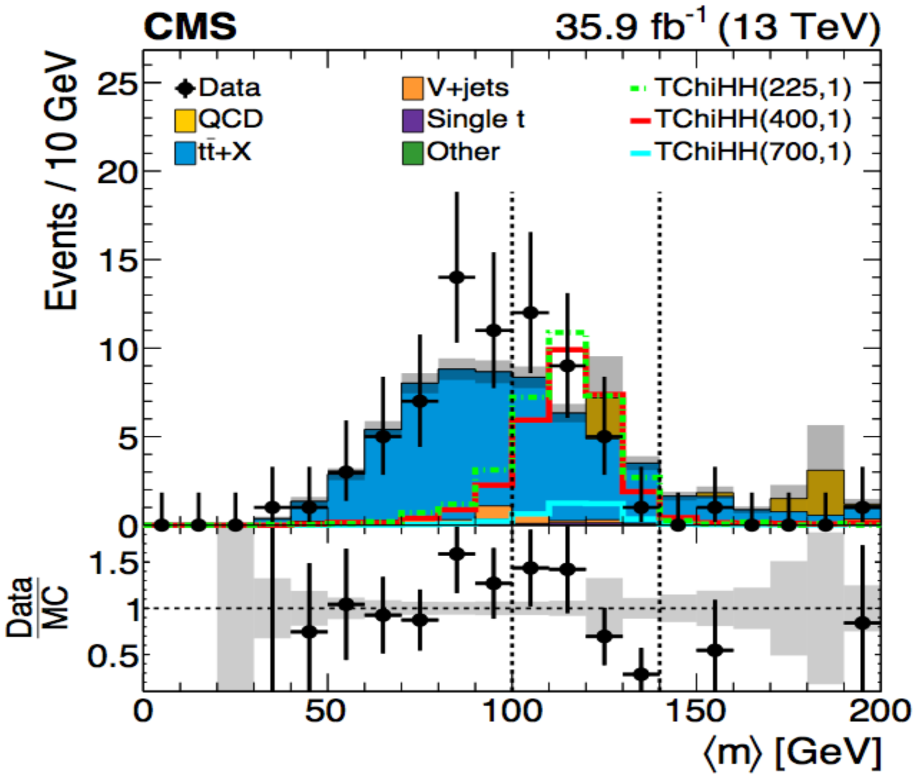


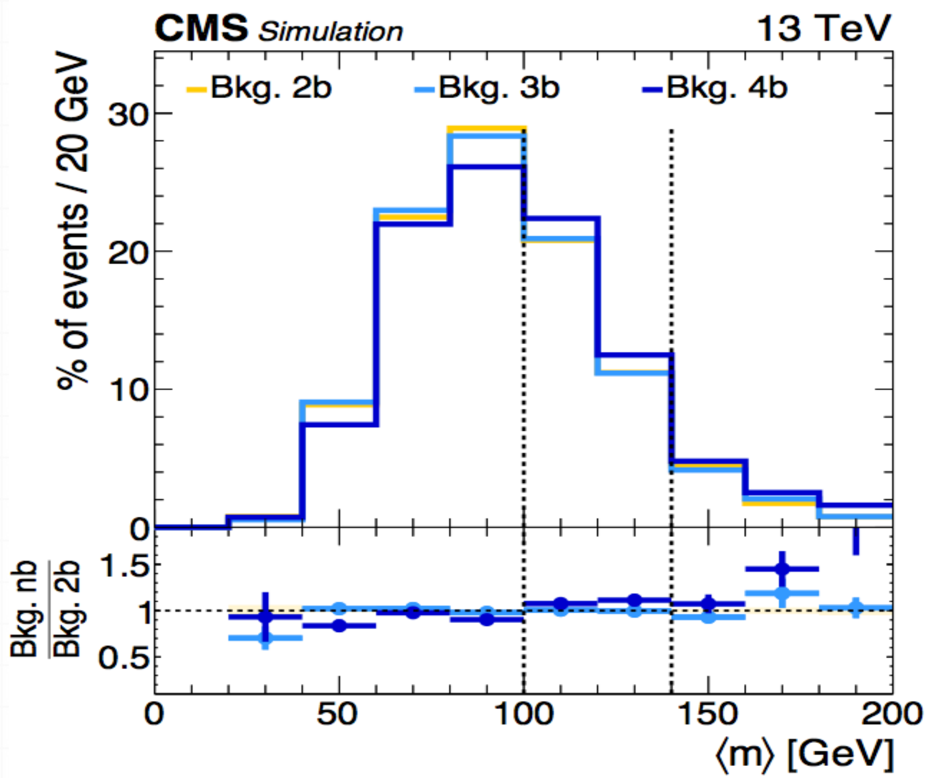
HH→4b + MET

PRD 97 (2018) 032007

- Higgs mass reconstruction:
  4 highest b-tagged jets, choose pairs with min Δm
- Dominant background: semi-leptonic tt production
  - Predicted by ABCD method with $N_{b\text{-jets}}$ and $\langle m_H \rangle$ variables
- 2 bins in #b-jets, 4 bins in p_T^{miss}

3 or ≥4 b-jets
Lepton veto
$p_T^{miss} > 150$ GeV
$100 < \langle m_H \rangle \leq 140$ GeV





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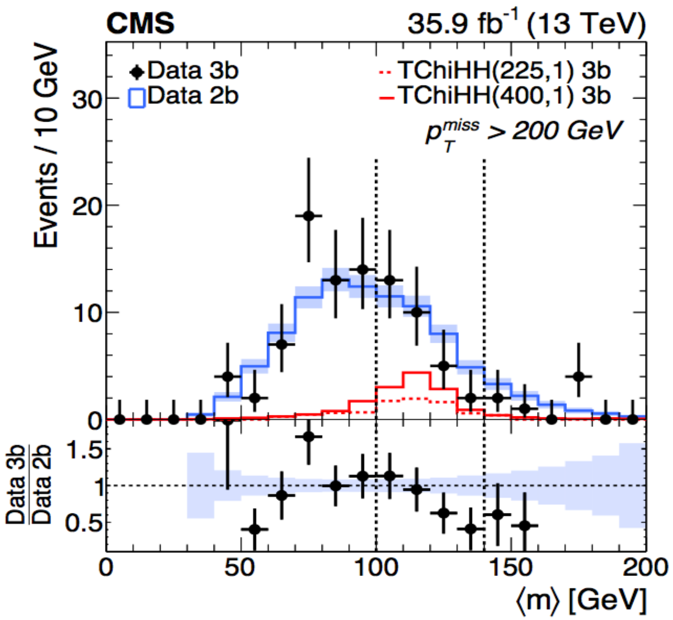
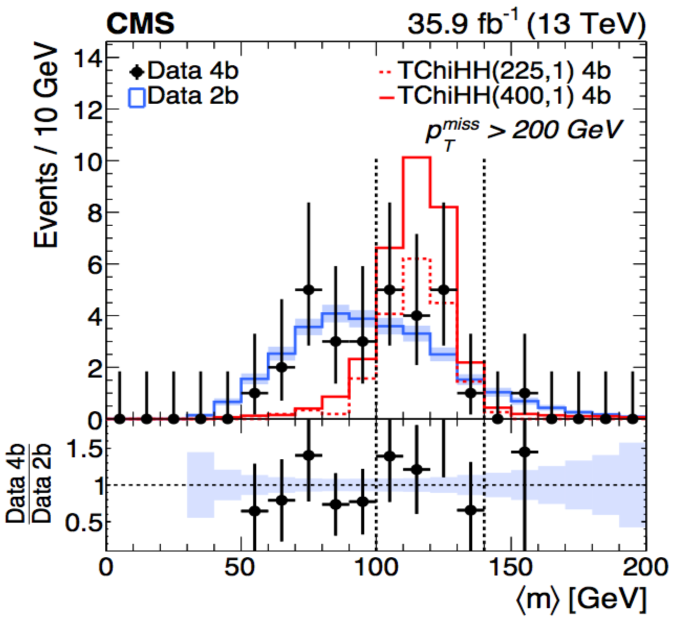
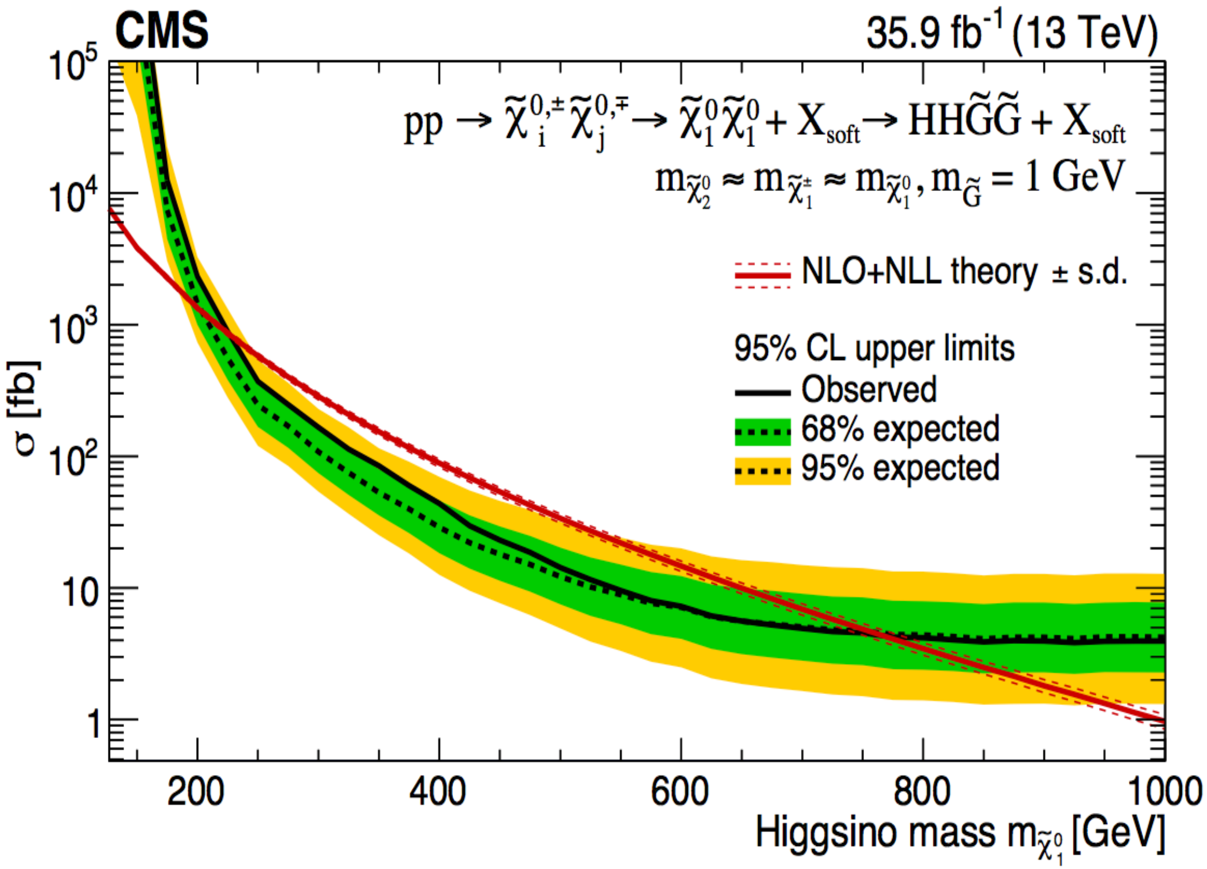
HH→4b + MET results







Excluded: m = 230 -770 GeV

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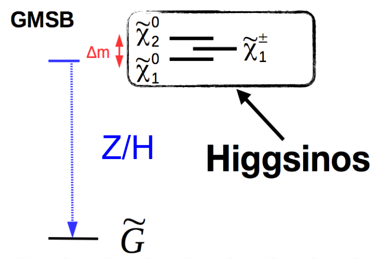
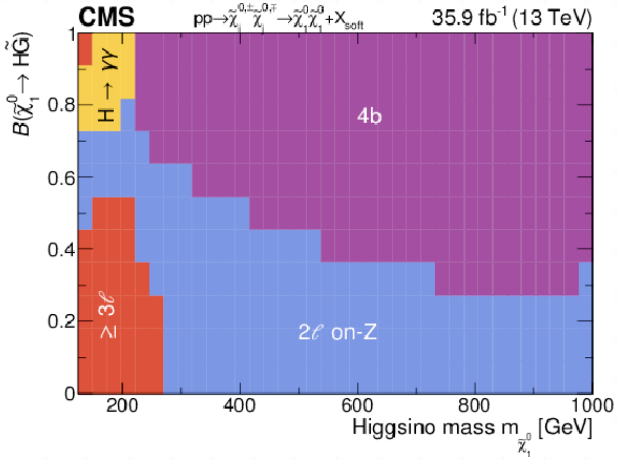
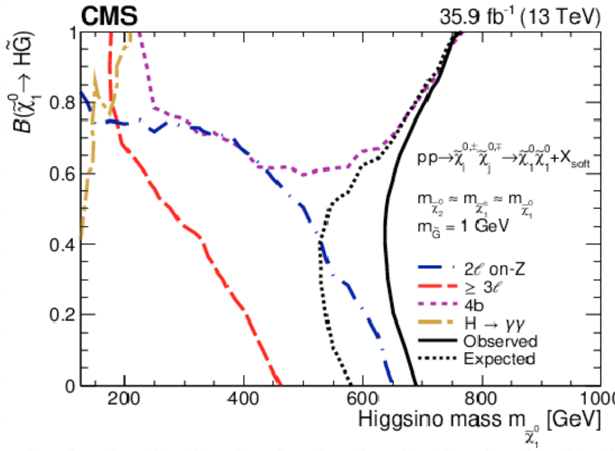
EW combination

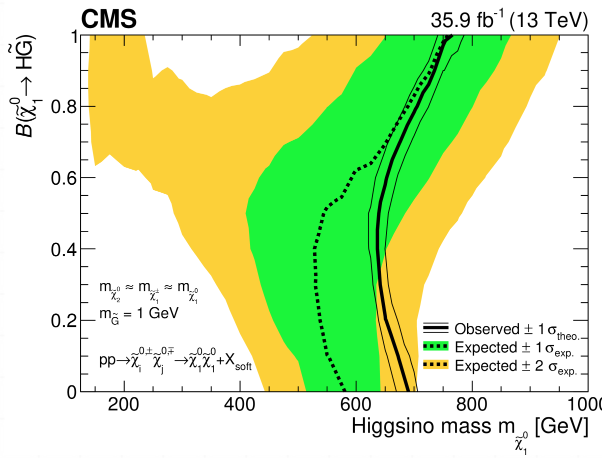
- Targets GMSB models with four quasi degenerate higgsino NLSPs ($\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_{1,2}$)
  - $\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1$ (+ low p_T particles)
  - $\tilde{\chi}^0_1 \rightarrow Z/H\ \tilde{G}$
- NLO+NLL pQCD cross-sections

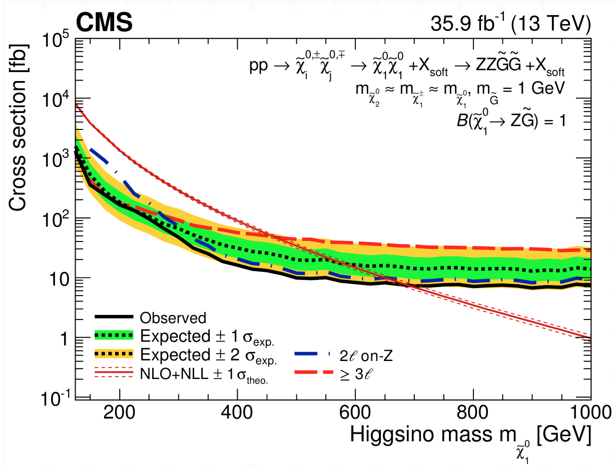


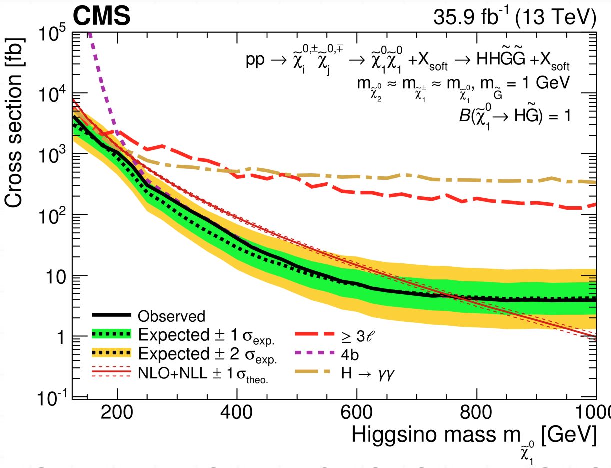
Search	Signal topology WZ	WH	ZZ	ZH	HH
1ℓ 2b		✓			
4b					✓
2ℓ on-Z	✓		✓	✓	
2ℓ soft	✓				
2ℓ SS, $\geq 3\ell$	✓	✓	✓	✓	✓
$H(\gamma\gamma)$		✓		✓	✓

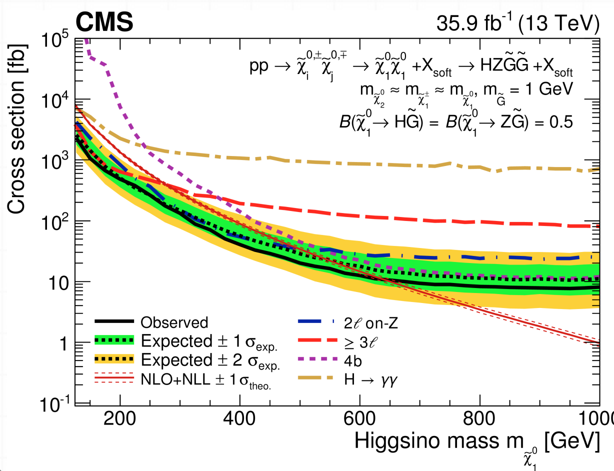








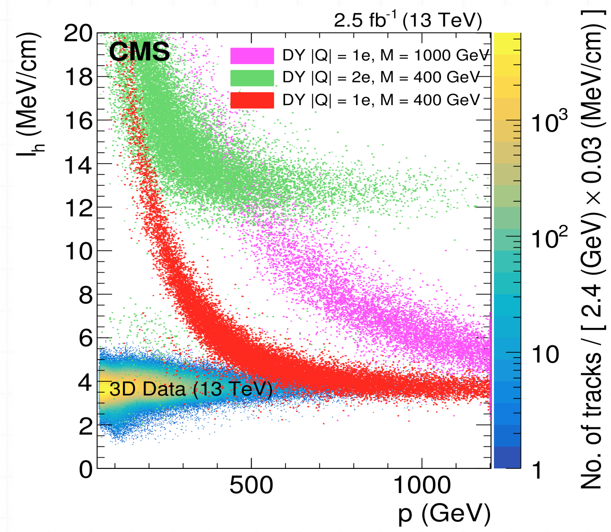


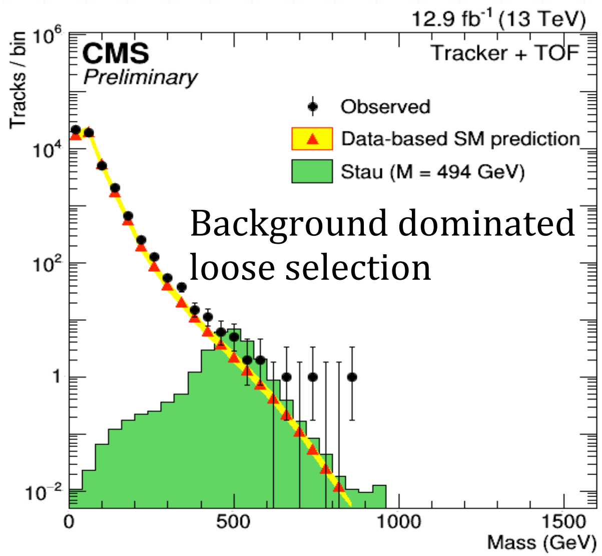


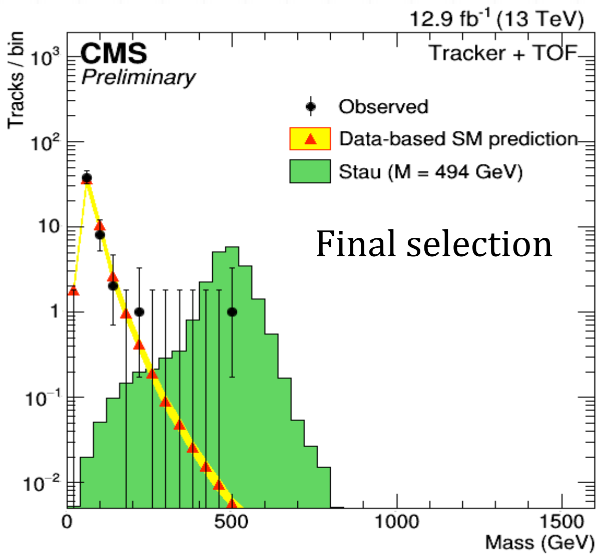
Long-lived scalar tau

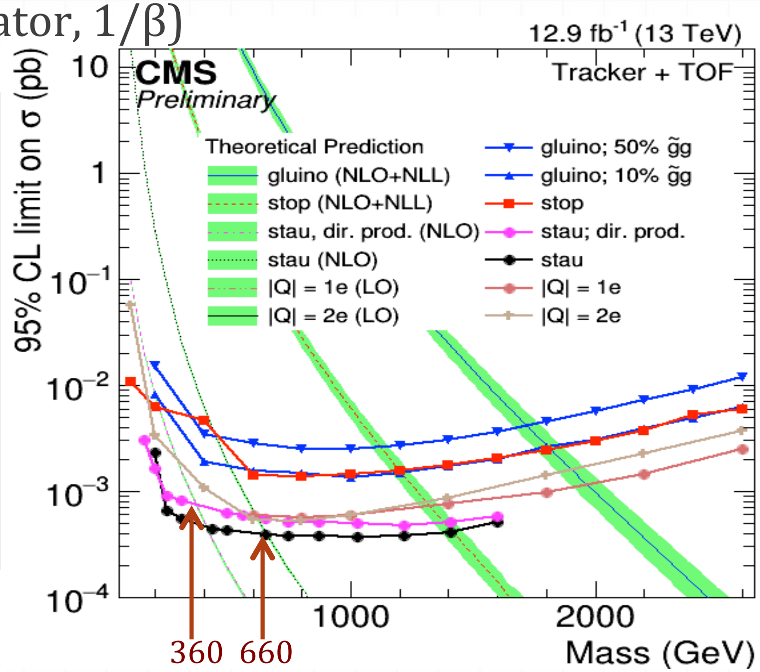
- NLSP can be long-lived in GMSB models
  - NLSP stau ($\tilde{\tau}_1$, predominantly $\tilde{\tau}_R$) from all sources (mostly gluino/squark cascade decays) [SPS7]
  - Direct EW stau pair production (model independent)
- Look for slow particles ($\beta \lesssim 0.9$)
  - High dE/dx in Si tracker along isolated, good quality track
  - Long TOF to muon chambers ($1/\beta > 1$, $\sigma_{1/\beta} < 0.15$)
- Two analysis: tracker only and tracker + TOF
- Trigger: $p_{T,\mu} > 10$ GeV or $p_{T,miss} > 170$ GeV (when LLP not reconstructed as muon)
- Background estimated by ABCD method (p_T, dE/dx estimator, $1/\beta$)

dE/dx estimator ($K \cdot m^2/p^2 + C$)









Summary

- Large number of searches targeting GMSB scenario
  - Most assumes prompt neutralino NLSP decays and look for γ/Z/H + MET
  - Long-lived NLSP gives characteristic signature in detector
    - Reconstruction challenging
- No signal seen yet
- Results constrain simplified models motivated by General Gauge Mediation
- More and more dedicated search to look in all corners
- Only a few % of total expected LHC data sample scrutinized
- A discovery might be at our reach in the coming years