Searches for SUSY with photons in the final state in CMS

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on behalf of the CMS collaboration

Motivation

SUSY with photons in the final state is well motivated:

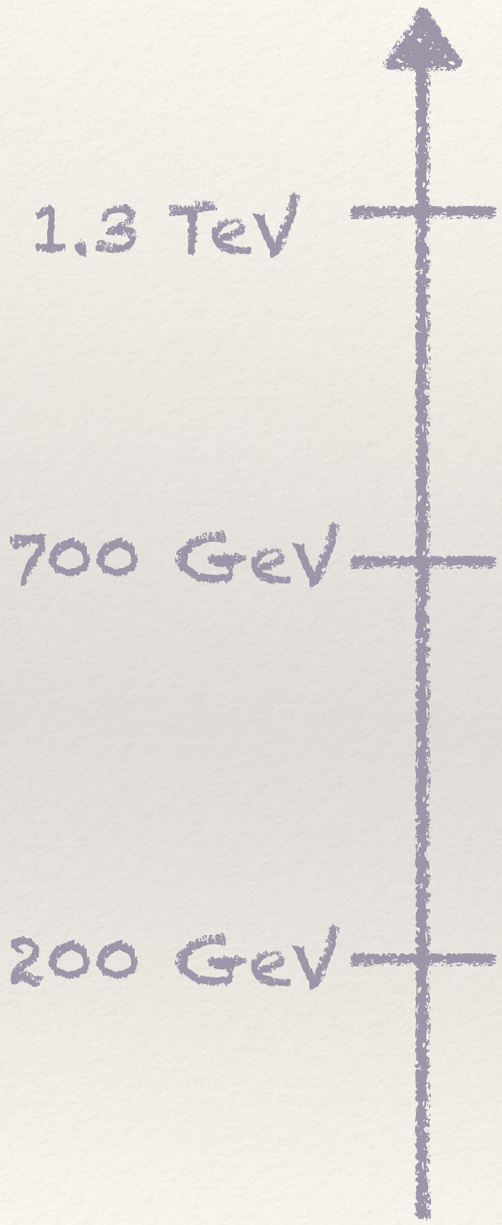
- *GMSB gluino / squark production predicts photons in the final state*

- *Higgs discovery → exciting new direction in SUSY searches involving Higgs in the decay chain (SUSY-EW production)*
- **h → γγ is a very clean and effective tagging signature for Higgs**

- **Will discuss both types of searches at CMS.**
  Including new result on inclusive higgs-aware (h→γγ) search using razor variables

Natural SUSY Spectrum

- **Why do we expect to see SUSY at the LHC?**
- **Assume SUSY is a natural theory. Provides bound on the SUSY spectrum**



gluino — **(2-loop contribution to the higgs mass)**

stop and sbottom — **(1-loop contribution to the higgs mass)**

neutralinos charginos — **(tree level contribution to the higgs mass)**

Higgsino mass is close to higgs mass

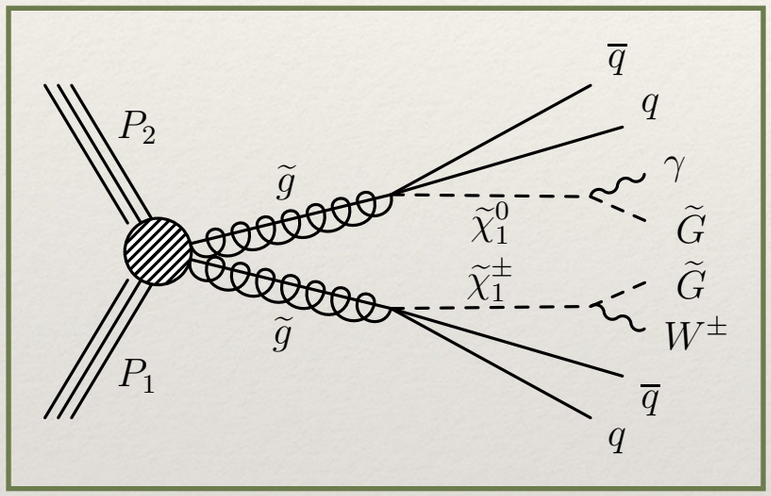
Considering a "natural" (tuning < 1%) SUSY, new particles accessible at the LHC energies

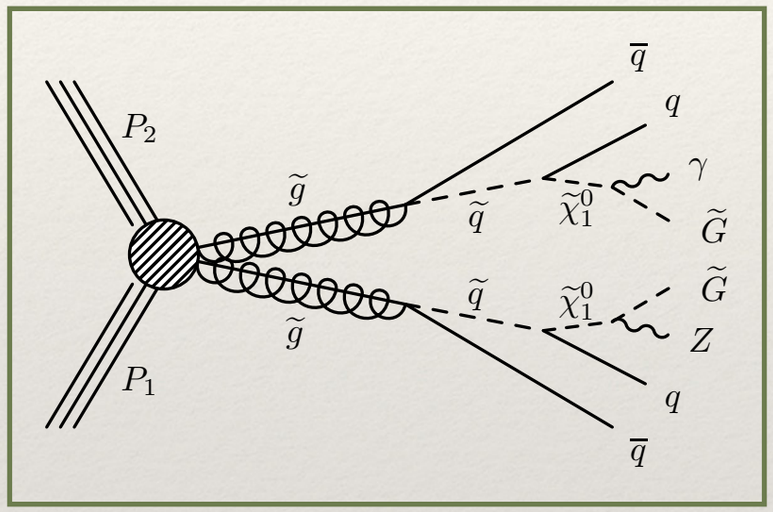
Gauge Mediated SUSY

- **SUSY with gauge-mediated symmetry breaking**
- **Gravitino is the LSP. Stable if R-parity is conserved**
- **If NLSP is a neutralino (bino/wino), photons with large p_T may be produced**

CMS-SUS-14-004, PRD 1507.02898

Single Photon Final State

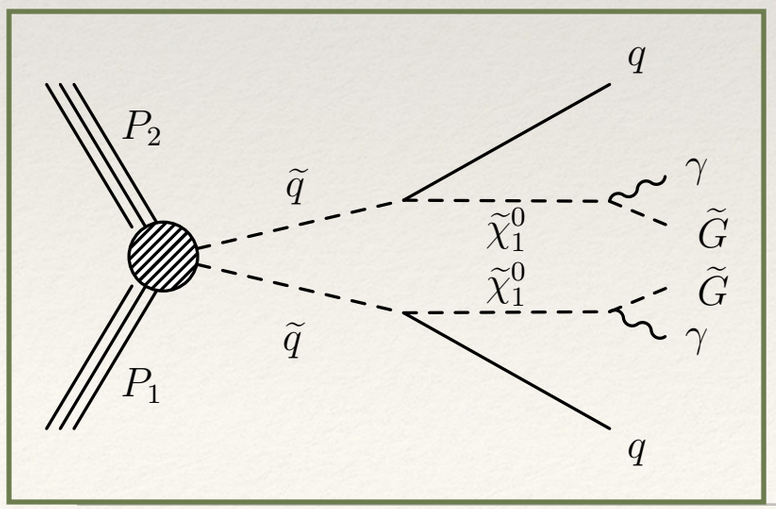


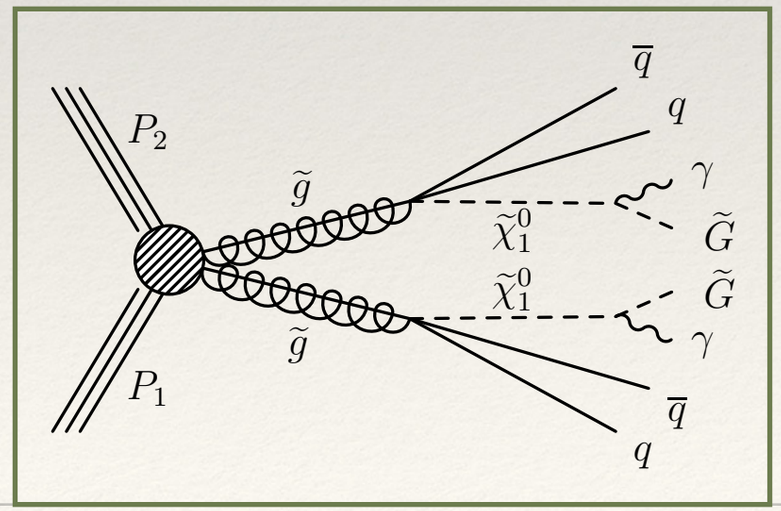


- **At least one photon (ɣ)**
- **Jets**
- **Missing E_T**

discriminating variable: E^{miss}_T

Double Photon Final State



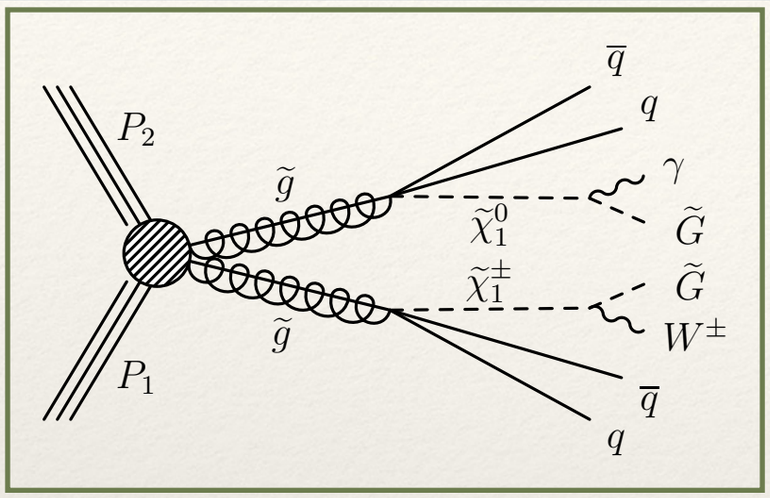


- **At least two photon (ɣ)**
- **Jets**
- **Missing E_T**

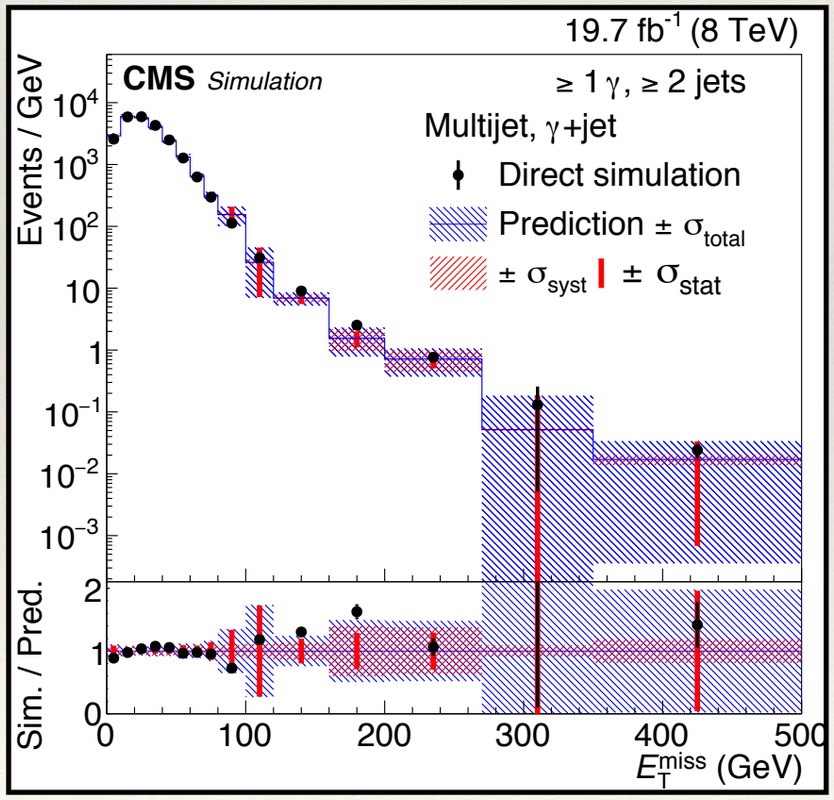
discriminating variable: Razor

Single Photon Analysis

CMS-SUS-14-004, PRD 1507.02898

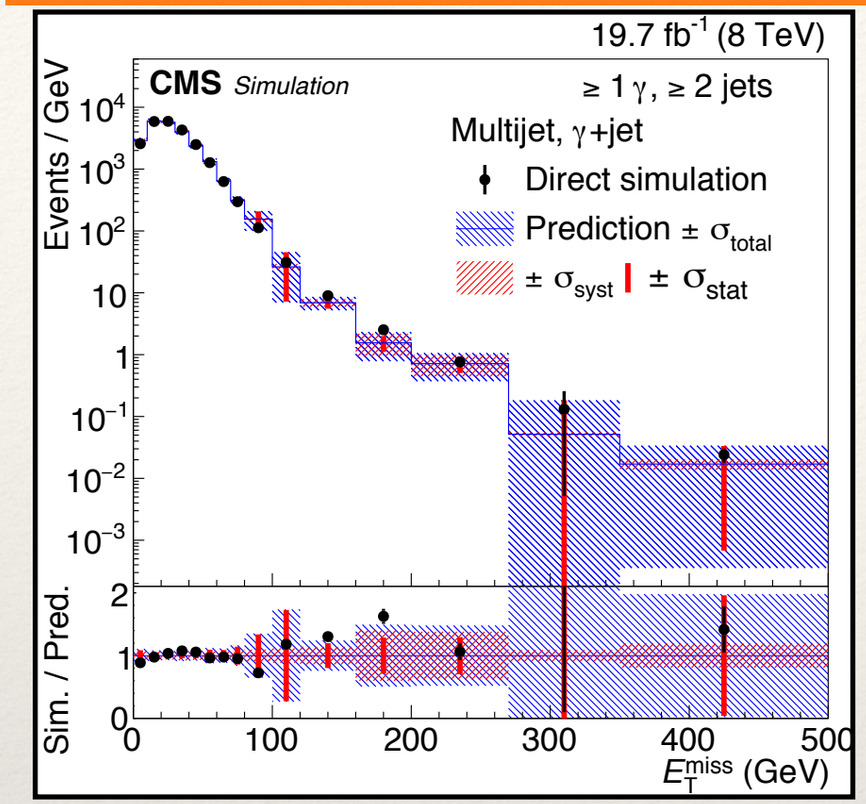


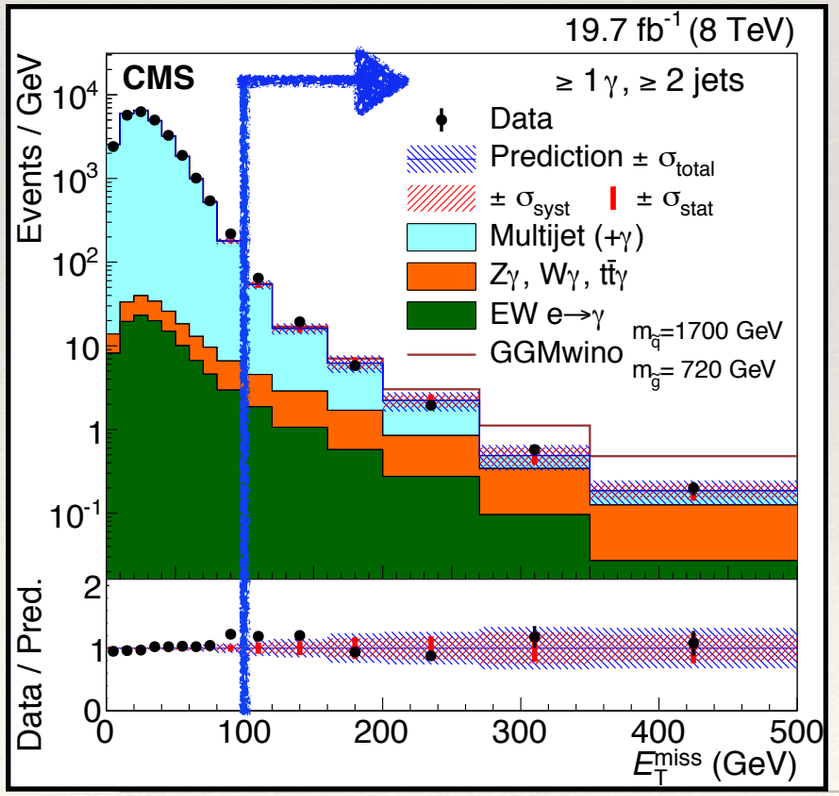
- **Selection:**
  - **At least one photon (ɣ): $P^*_T > 110$ GeV**
  - **At least two jets: $P_T > 30$ GeV**
  - **$H^*_T > 500$ GeV (including ɣ)**



- **SM backgrounds**
  - *QCD multijet and ɣ+jets events*
  - *W+jets and tt + jets (EW): real E^{miss}_T, e →ɣ*
  - *ɣW+jets, ɣZ+jets, ɣtt + jets*
- **Discriminating variable**
  - **$E^{miss}_T > 100$ GeV, 6 bin categories**

Single Photon Analysis





CMS-SUS-14-004, PRD 1507.02898

Background Prediction

- Use a γ^{loose} (relax isolation) control sample.
  Obtain correction factors for E^{miss}_T .
  Predict Multijet and γ+jet
- Use a γ^{pixel} (pixel seed match) control sample.
  Predict EW scaling E^{miss}_T distribution by $f_{e\to\gamma}$

Results

- Obtain Full background prediction
- Search $E^{miss}_T > 100$ GeV in 6 bins .
- Look for excesses in the tail of E^{miss}_T

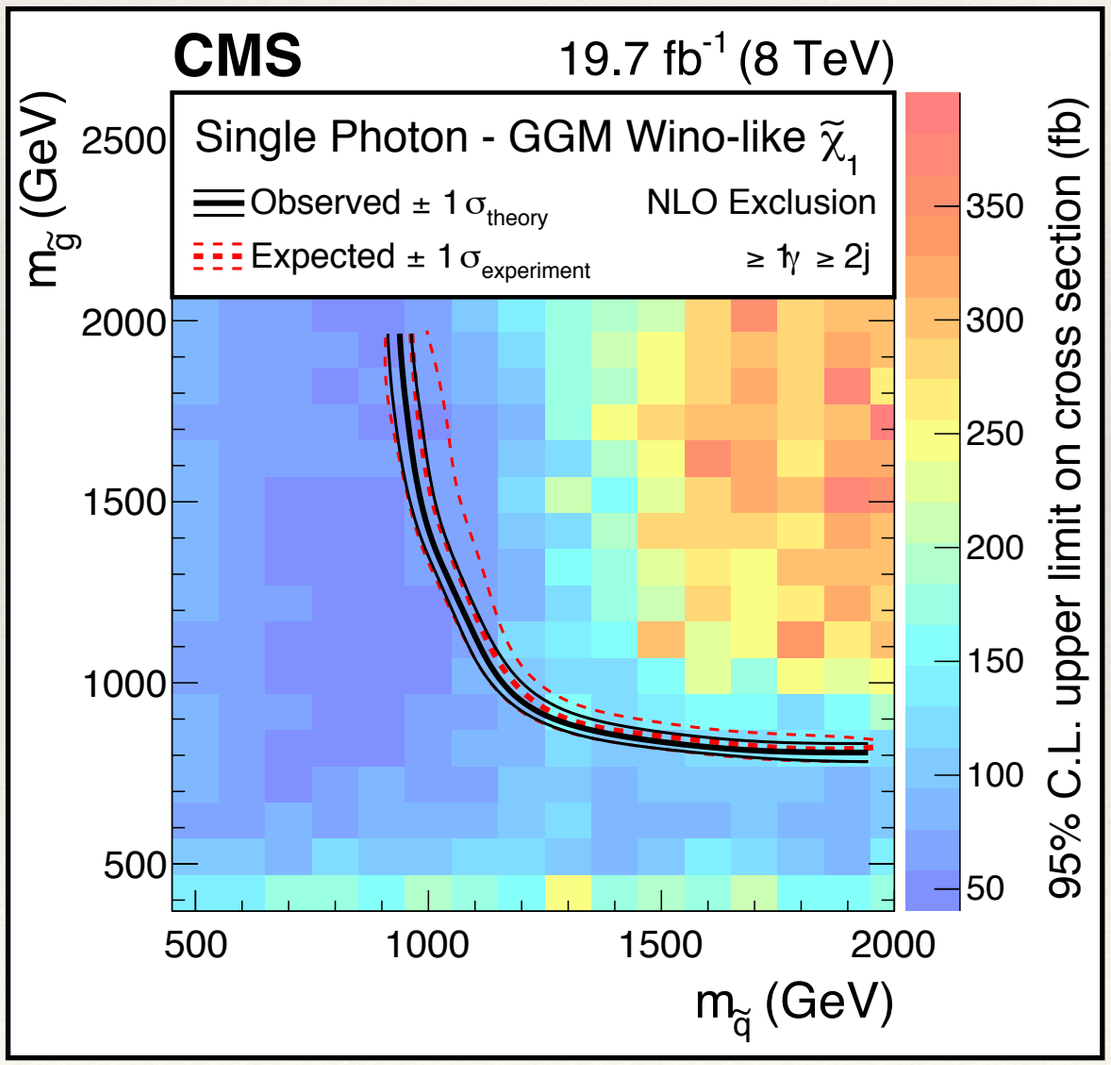
No excess found in any E^{miss}_T bin

Single Photon Analysis

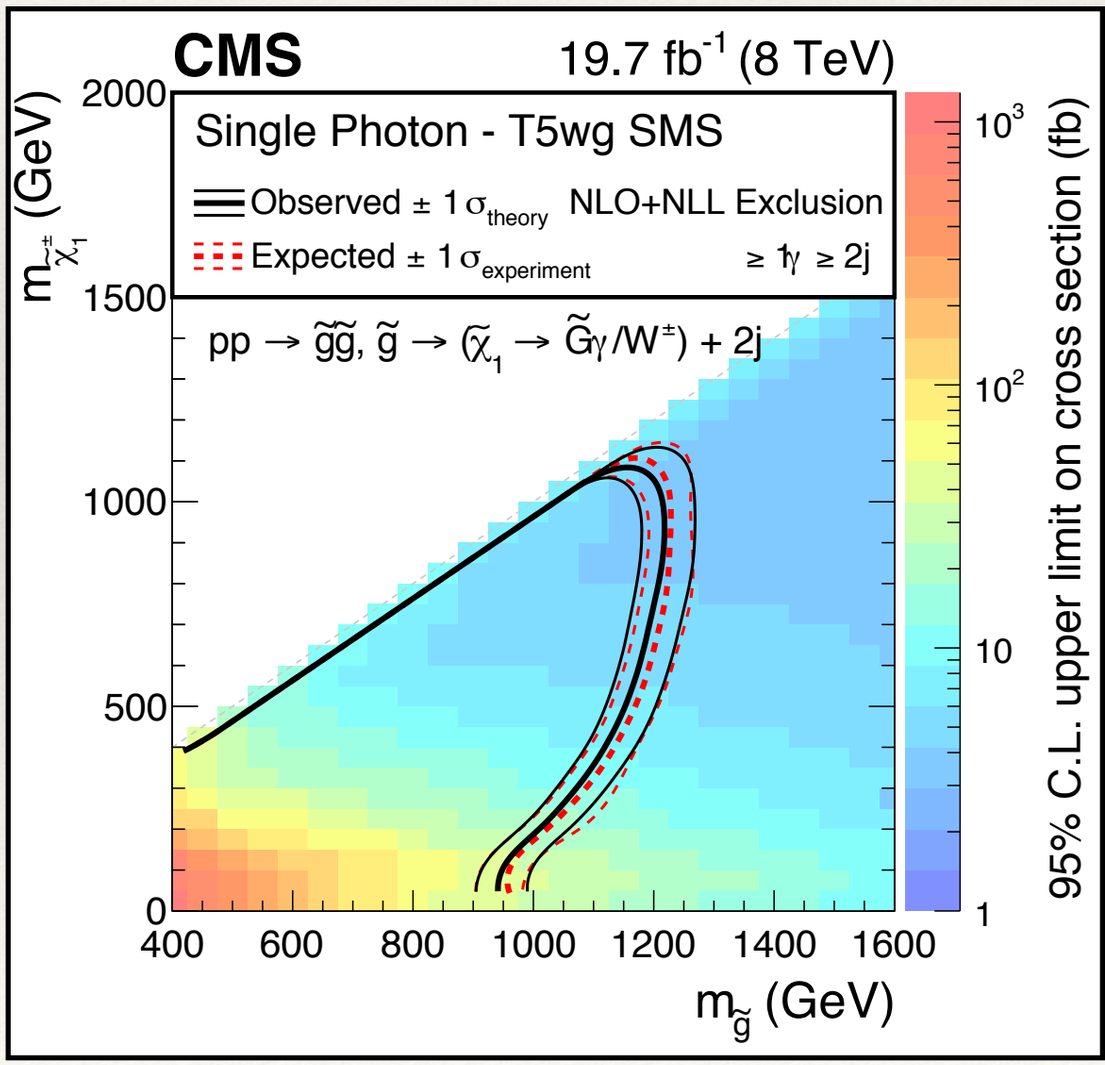
CMS-SUS-14-004, PRD 1507.02898

- **No observed excess**
- **Multi-channel counting exp.**
- **We set 95% CLs limits**

- *GGM-Wino*
  - *m_{gluino} >~ 1 TeV, m_{squark} ~ 0.8 TeV*

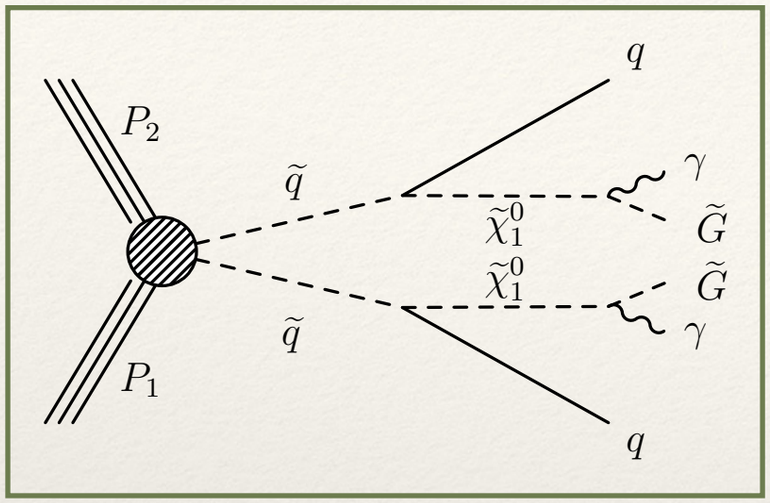


- *SMS T5wg*
  - *m_{gluino} >~ 1 TeV*

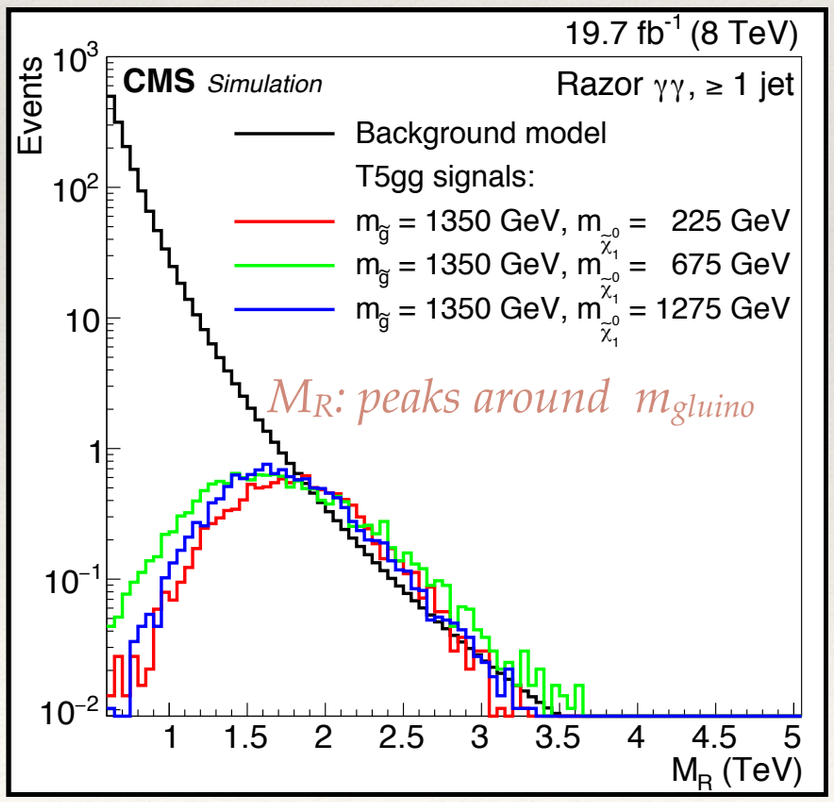


Double Photon Analysis

CMS-SUS-14-004, PRD 1507.02898



- **Selection:**
  - **At least two photons (ɣ): $P^{lead}_T > 30$, $P^{sublead}_T > 22$ GeV**
  - **At least one jet: $P_T > 40$ GeV, $|\eta| < 2.5$, $\Delta R(\gamma_{(1,2)}, j_i) > 0.5$**

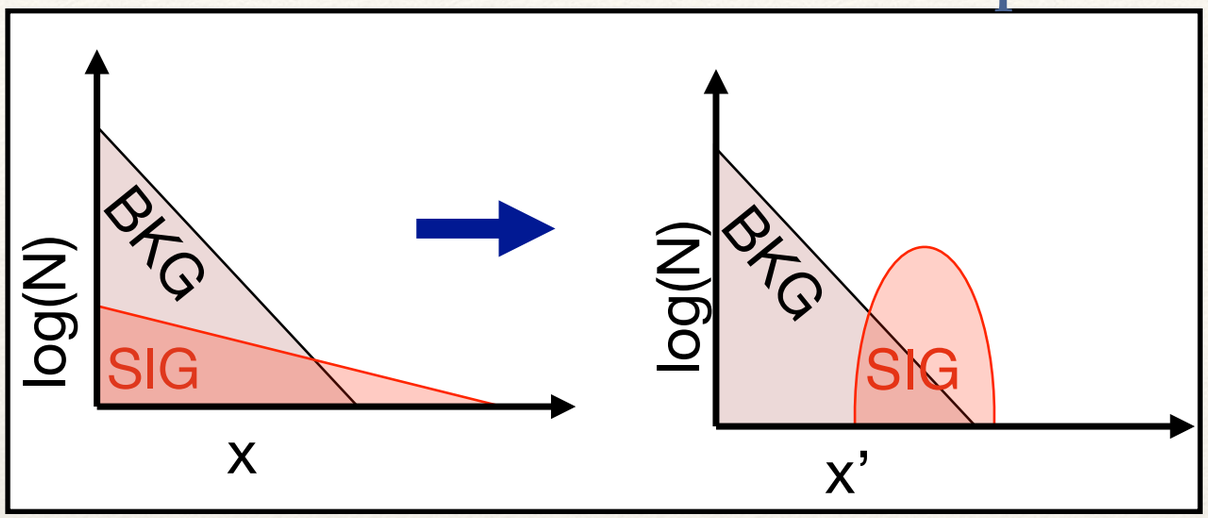


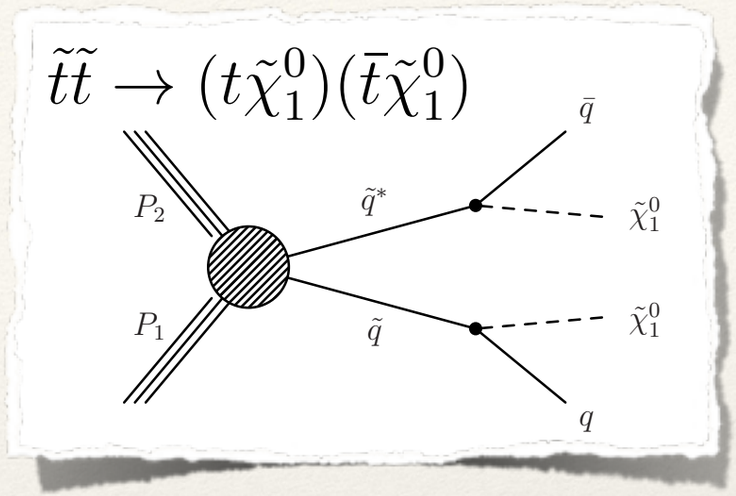
- **Standard Model backgrounds**
  - **QCD multijet, ɣ+jets events**
  - **W+jets and tt + jets (EW): real E^{miss}_T, e →ɣ *(negligible)***
- **Discriminating variables**
  - **Razor variables: M_R *(mass scale)* and R^2 *(energy imbalance)***

- **Search region: $M_R > 600$ GeV && $R^2 > 0.2$ *(high R^2)***

Razor Variables (M_R, R^2)

Transform a "tail" search into a ~bump search

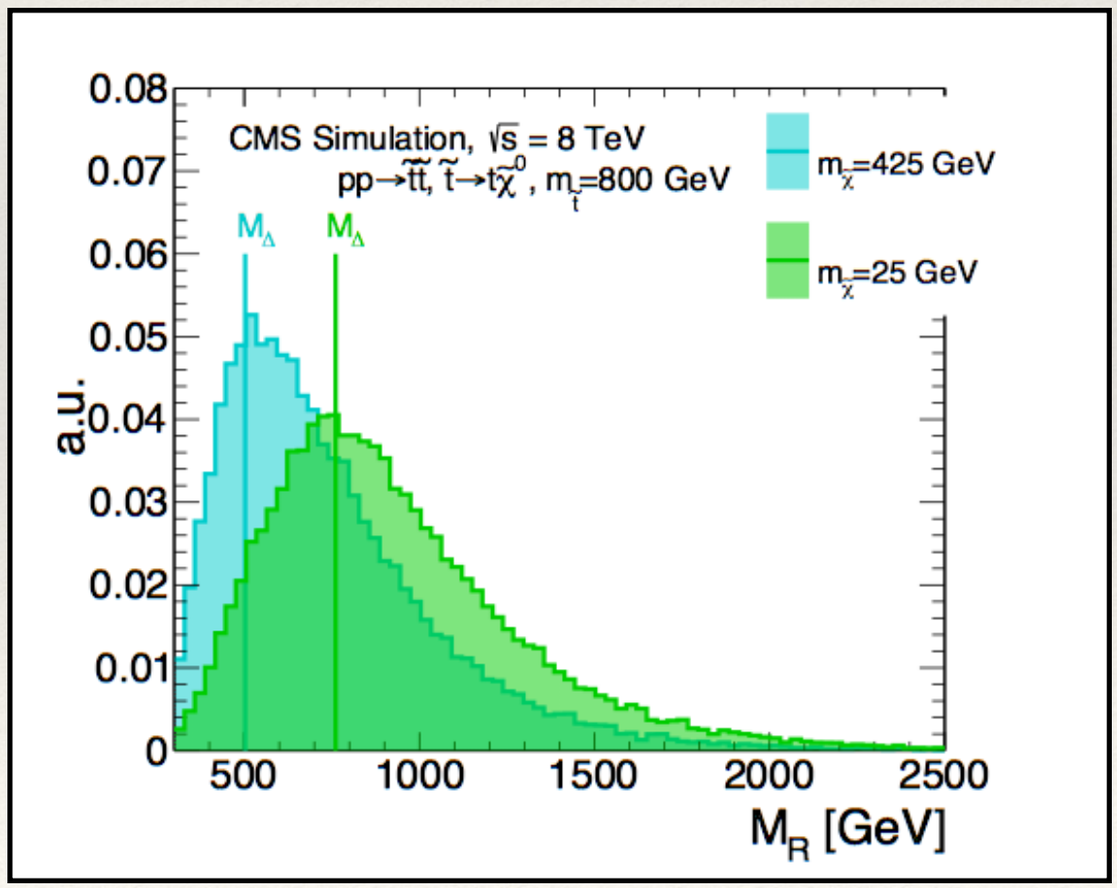




$$M_R = \sqrt{(|\vec{p}_{j_1}| + |\vec{p}_{j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

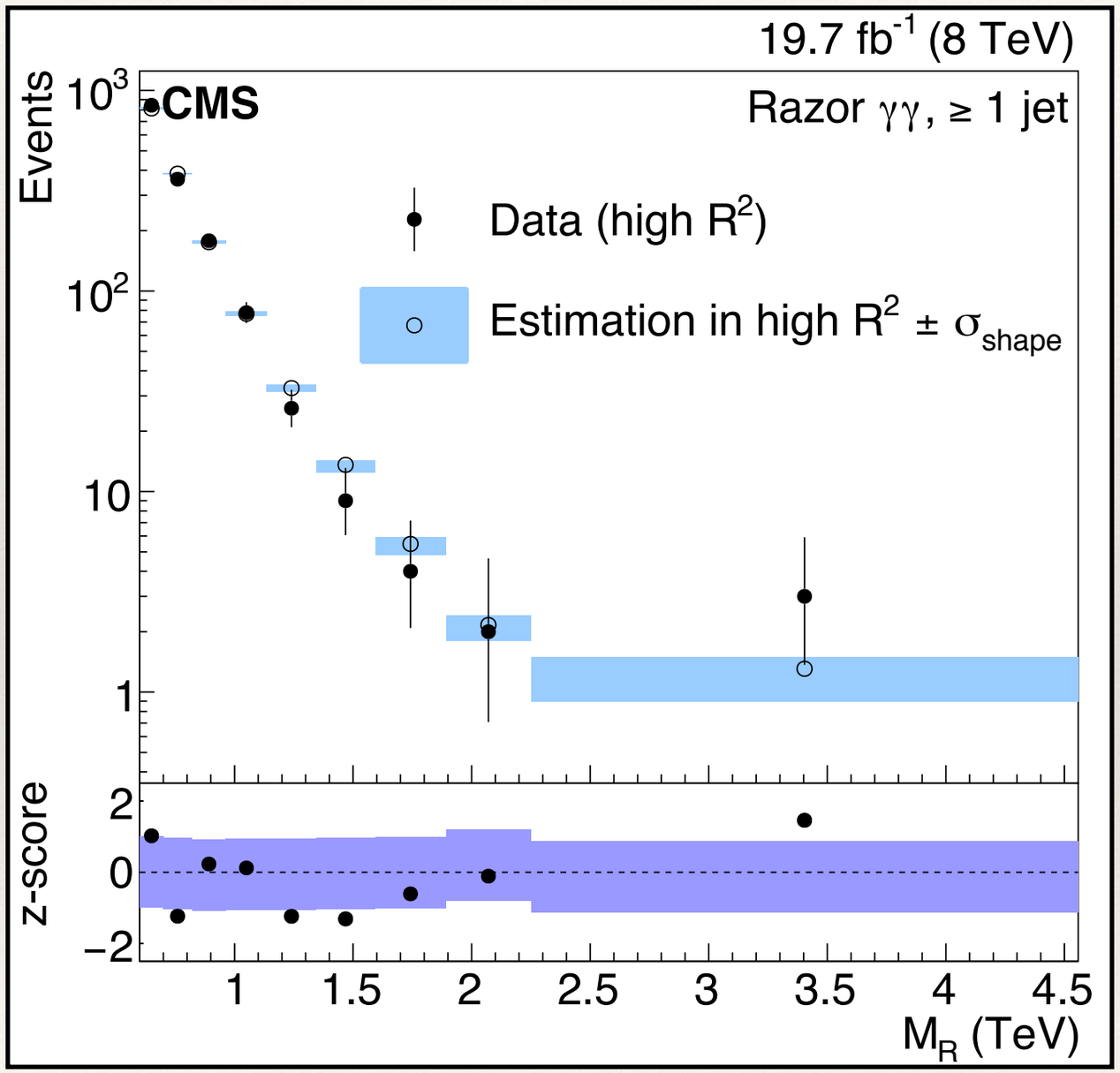
$$M_\Delta = \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}$$

- M_R peaks at M_Δ (new mass scale)
- R^2 contains information about the momentum imbalance in the event
- Cutting on R^2 increases S/B



Double Photon Analysis

CMS-SUS-14-004, PRD 1507.02898



Results

- **Extrapolate fit shape to signal region**
- **Look for excess in M_R > 600 GeV**

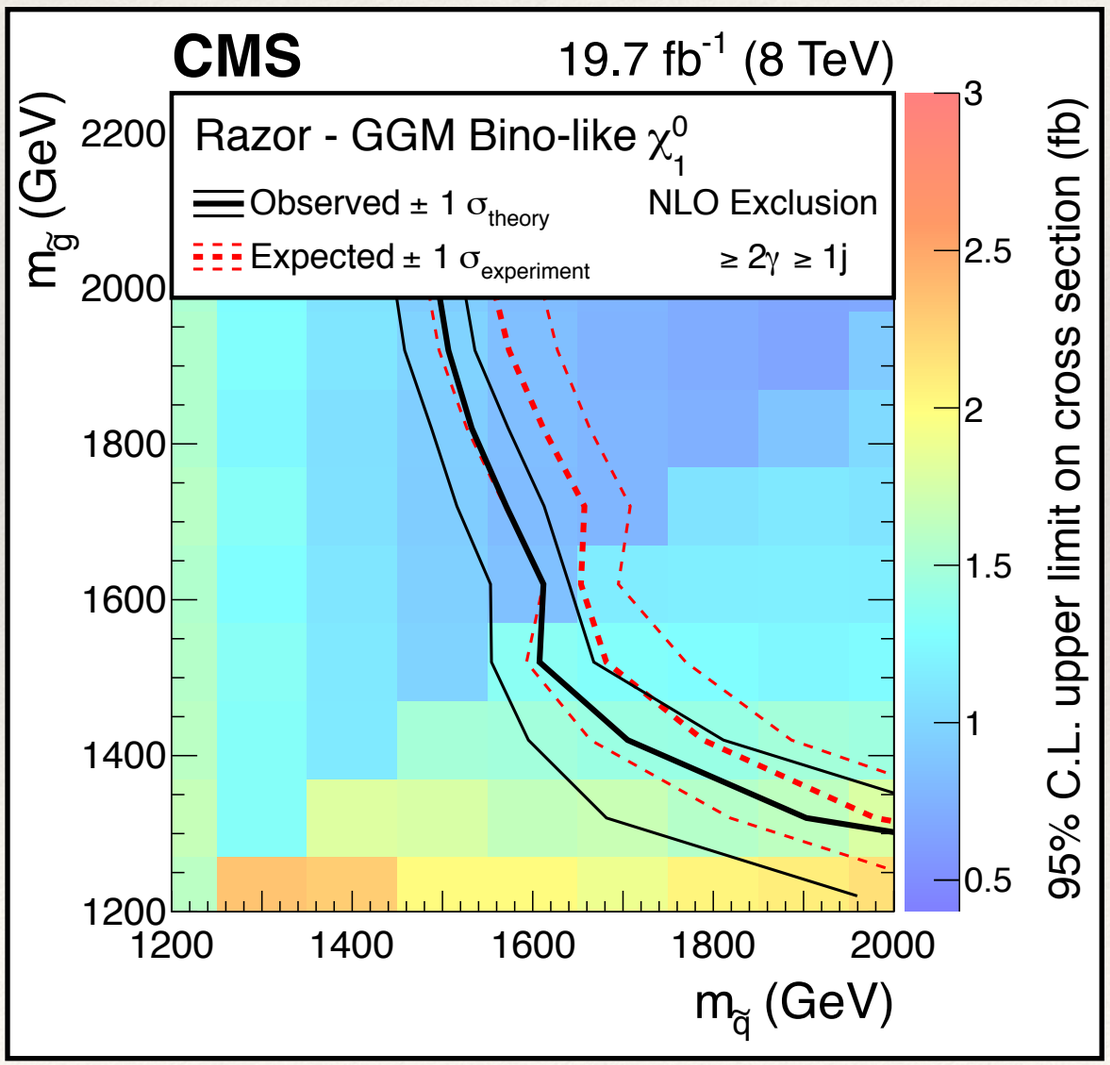
No excess in any M_R bin.

Double Photon Analysis

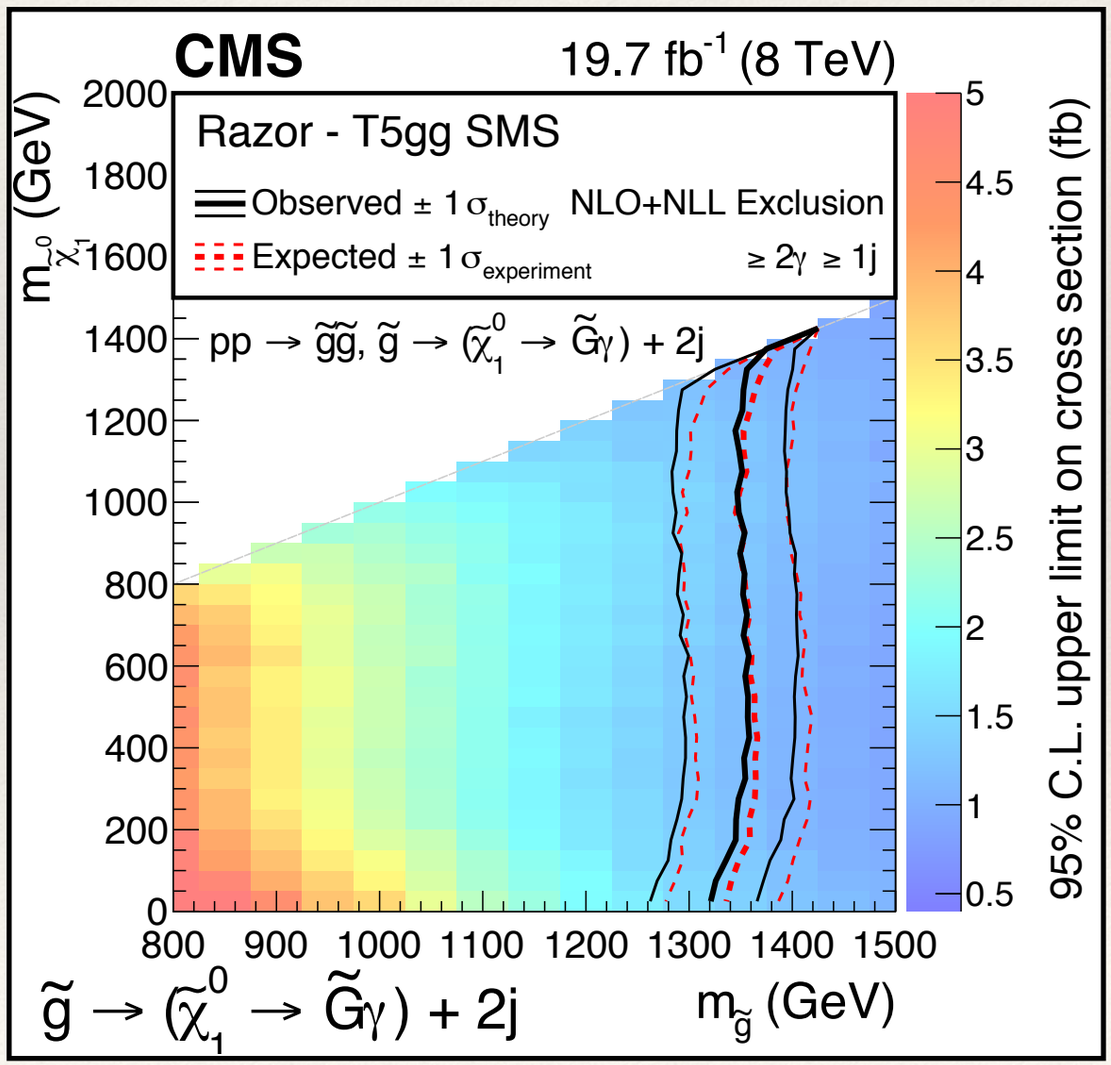
- **No observed excess**
- **multi-channel counting exp.**
- **We set 95% CLs limits**

CMS-SUS-14-004, PRD 1507.02898

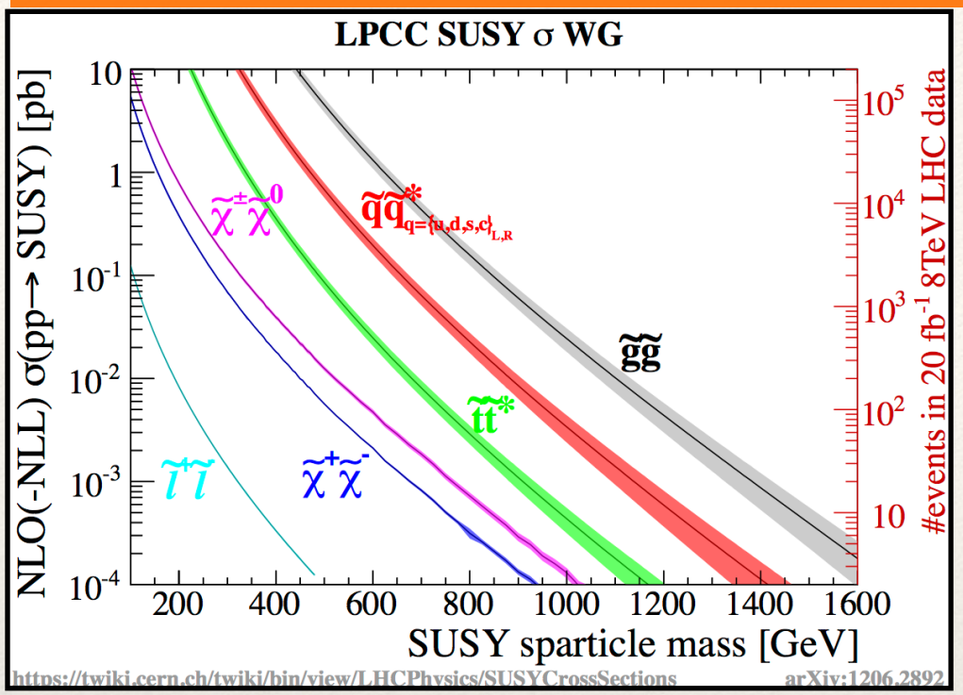
- *GGM-Bino*
  - $m_{gluino} >\sim 1.5$ *TeV,* $m_{squark} >\sim 1.4$ *TeV*

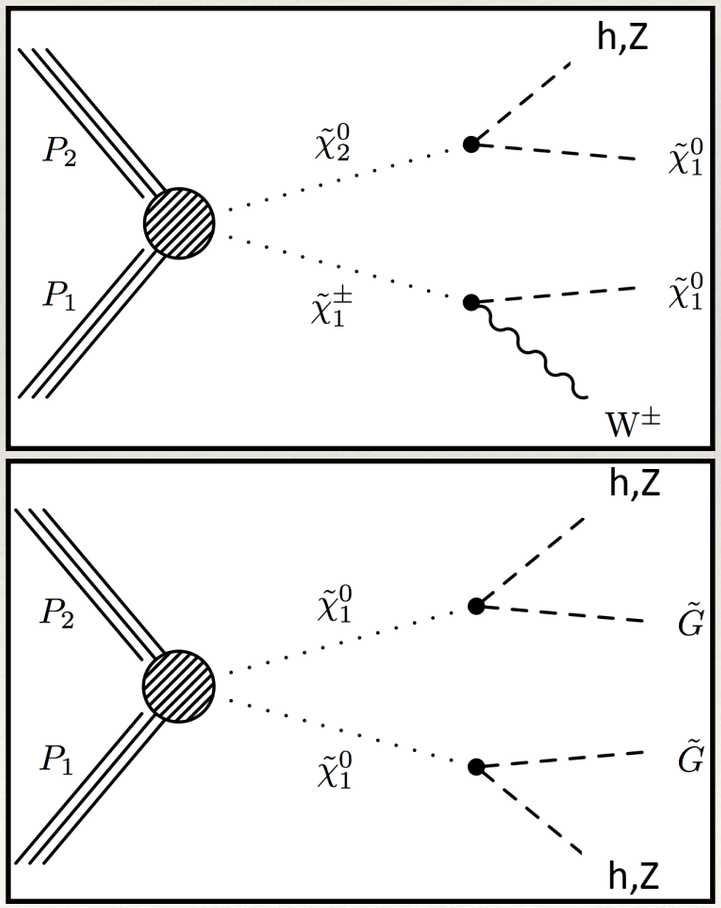


- *SMS T5gg*
  - $m_{gluino} >\sim 1.3$ *TeV*



Higgs Aware SUSY



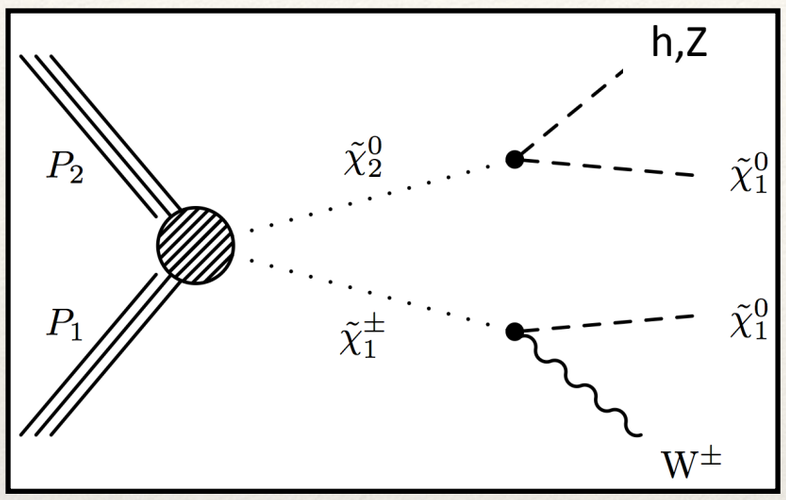


Discovery of the higgs boson enhances the LHC SUSY program

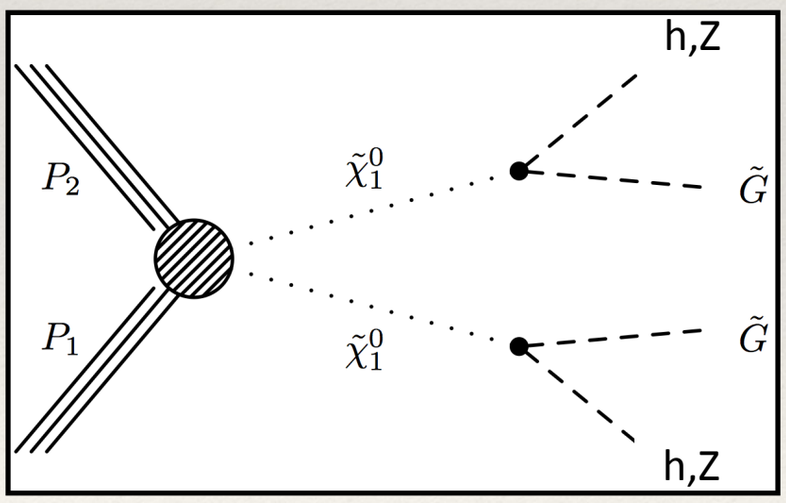
- **Search for electroweak SUSY production complements typical searches for strongly produced SUSY**
- **Characterized by: fewer jets & more W, Z, Higgs in decay chain**
- **h →γγ is particularly interesting : a narrow resonance**
- ***Final state: photons, jets and/or* leptons**

Electroweak SUSY Searches ($h \rightarrow \gamma\gamma$)

CMS-SUS-14-002, PRD 90, 092007 (2014)



- **Selection:**
  - At least two photons (γ): $P^{lead}_T > 40$, $P^{sublead}_T > 25$ GeV
  - Both photons in ECAL barrel, i.e $|\eta| < 1.44$
  - Two highest P_T photons form higgs candidate

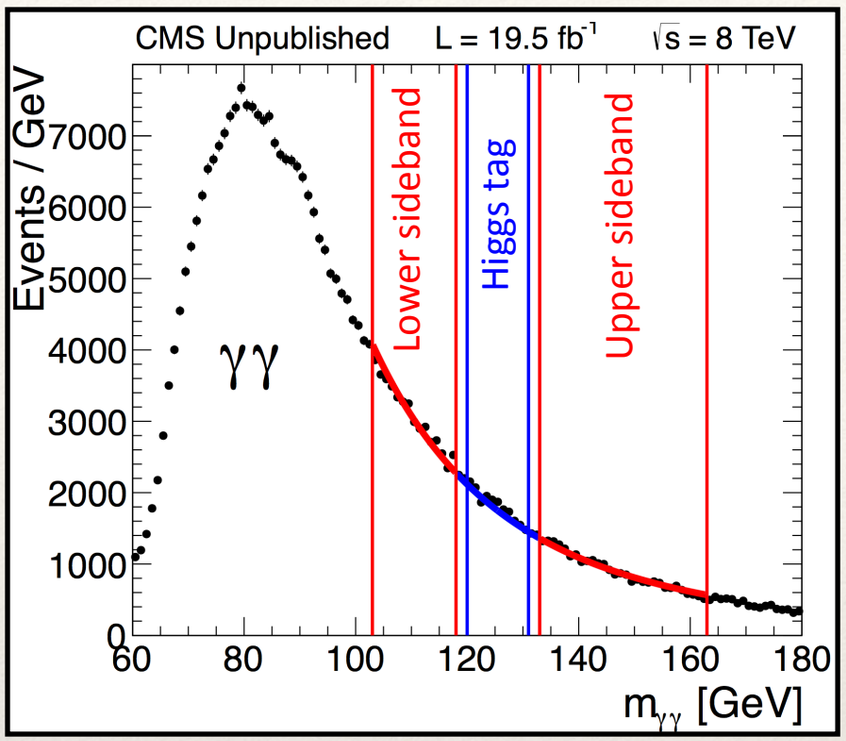


- SM backgrounds
  - QCD multijet events: mismeasured E^{miss}_T + fakes
  - QCD multijet + γ/γγ: mismeasured E^{miss}_T *(dominant)*
  - SM-higgs: real E^{miss}_T, *(sub-leading)*

- Discriminating variables
  - Depends on the final state:
    - $hh \rightarrow \gamma\gamma bb$, S^h_T: scalar sum of higgs cand. P_T
    - hZ, hW → γγ + 2jets: E^{miss}_T
    - hZ, hW → γγ + leptons: missing transverse mass M_T

Electroweak SUSY Searches ($h \rightarrow \gamma\gamma$)

CMS-SUS-14-002, PRD 90, 092007 (2014)

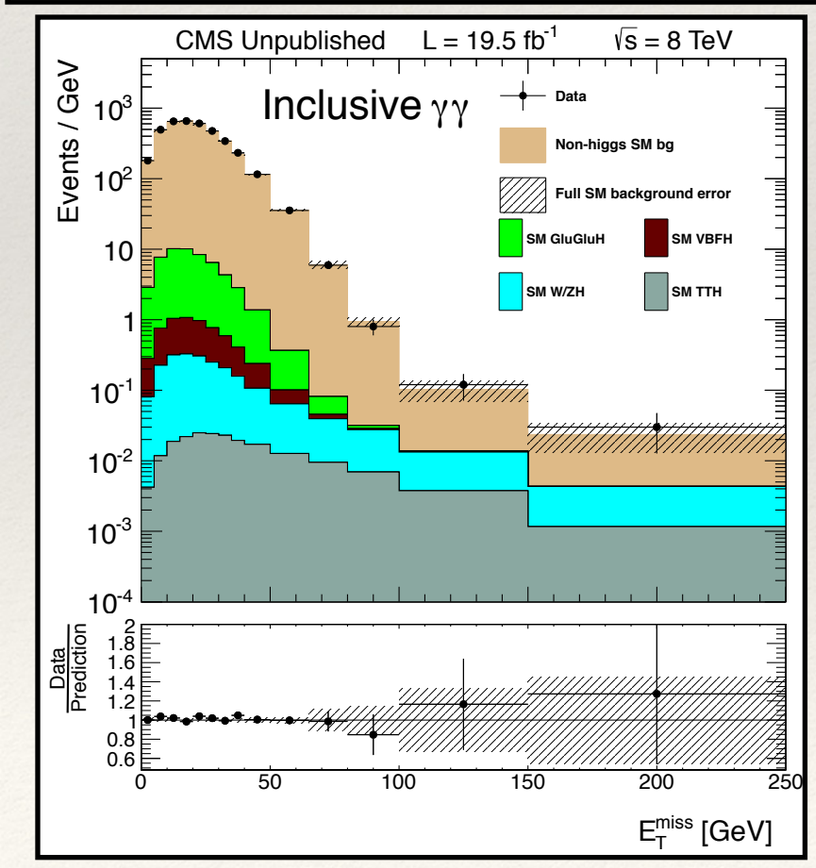


Background Prediction

- **Define sideband region:**

  $m_{\gamma\gamma} \ni$ [{103-118}, {133-163}] GeV

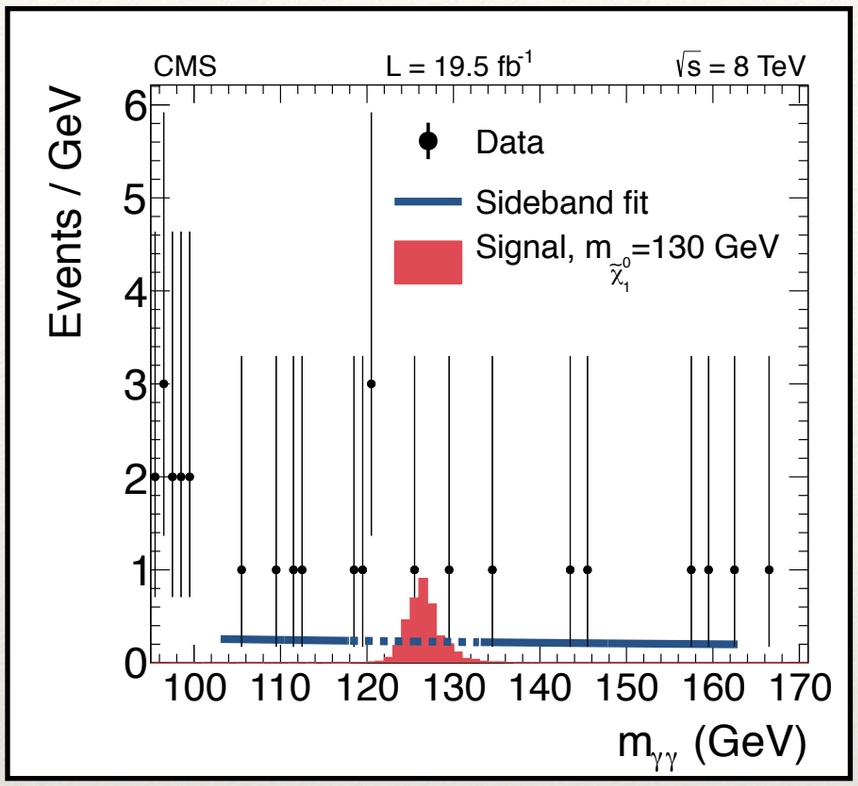
- **Fit sidebands with a power law function**



- **Use fit to extrapolate from the sidebands to the signal region**
- ***Extrapolate chosen search variable distribution in sidebands to signal region***
- **Estimate SM-Higgs using Monte Carlo**

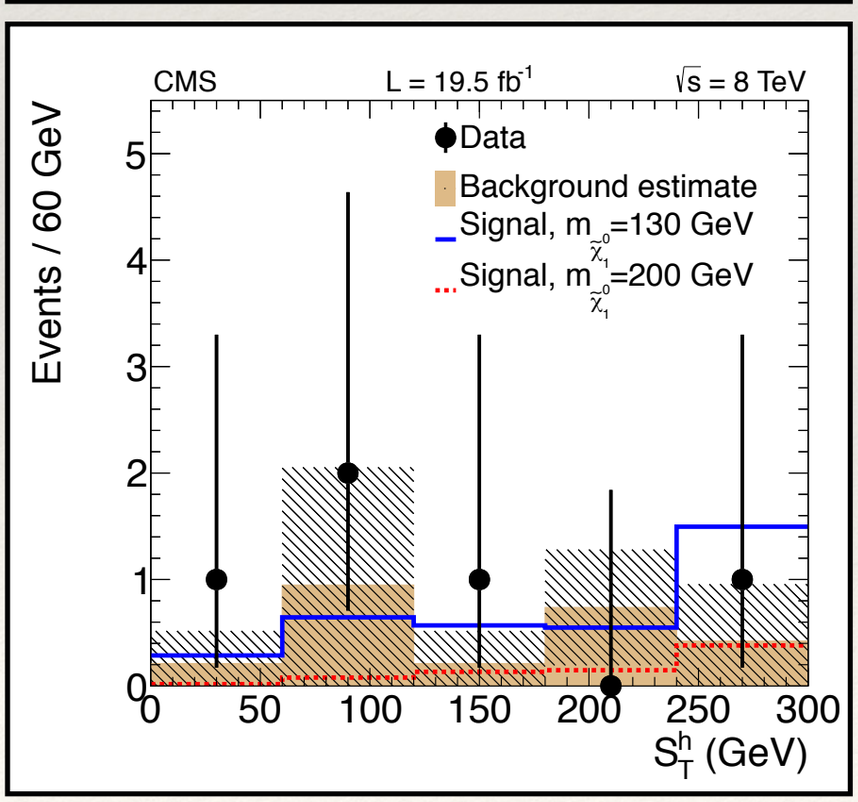
Electroweak SUSY Searches ($hh \rightarrow \gamma\gamma bb$)

CMS-SUS-14-002, PRD 90, 092007 (2014)



Search for double higgs production

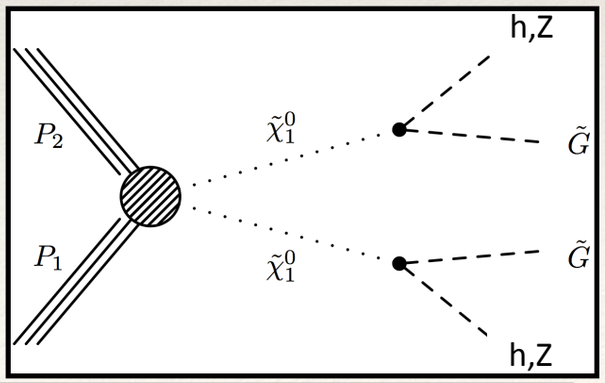
- **Reconstruct one higgs candidates through:**
  - **$h \rightarrow \gamma\gamma$ decay, $m_{\gamma\gamma} \ni [103\text{-}163]$ GeV**
  - **$h \rightarrow bb$ decay, $m_{bb} \ni [95\text{-}155]$ GeV**
- **Construct S^h_T, scalar sum P_T of the two h's**



- ***Background prediction by extrapolating from $m_{\gamma\gamma}$ sidebands.***

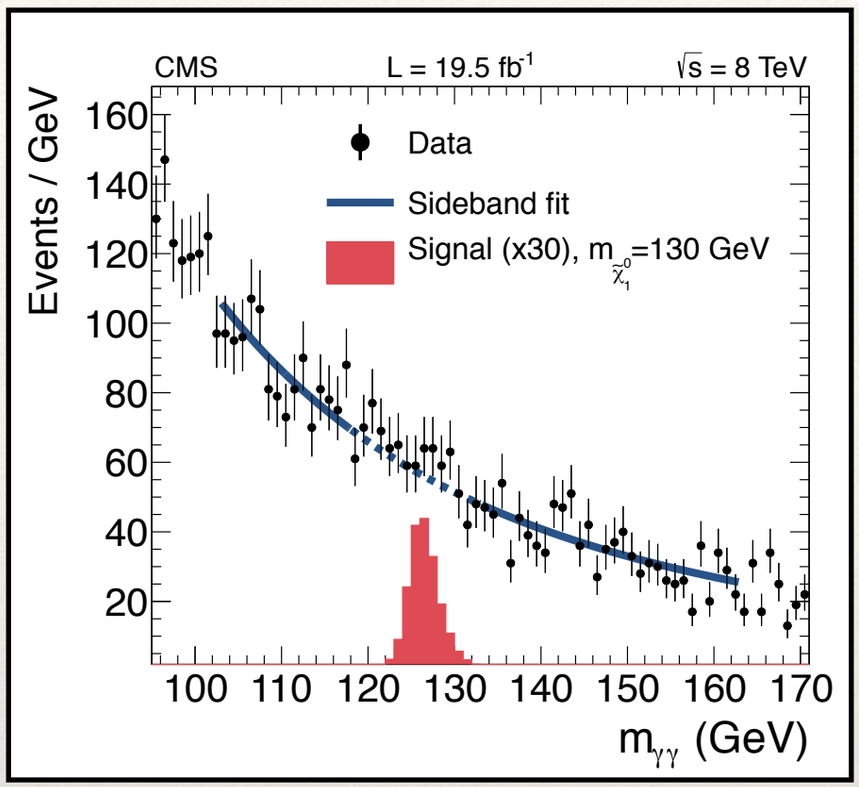
No significant excess observed

SM-Higgs background from MC: negligible



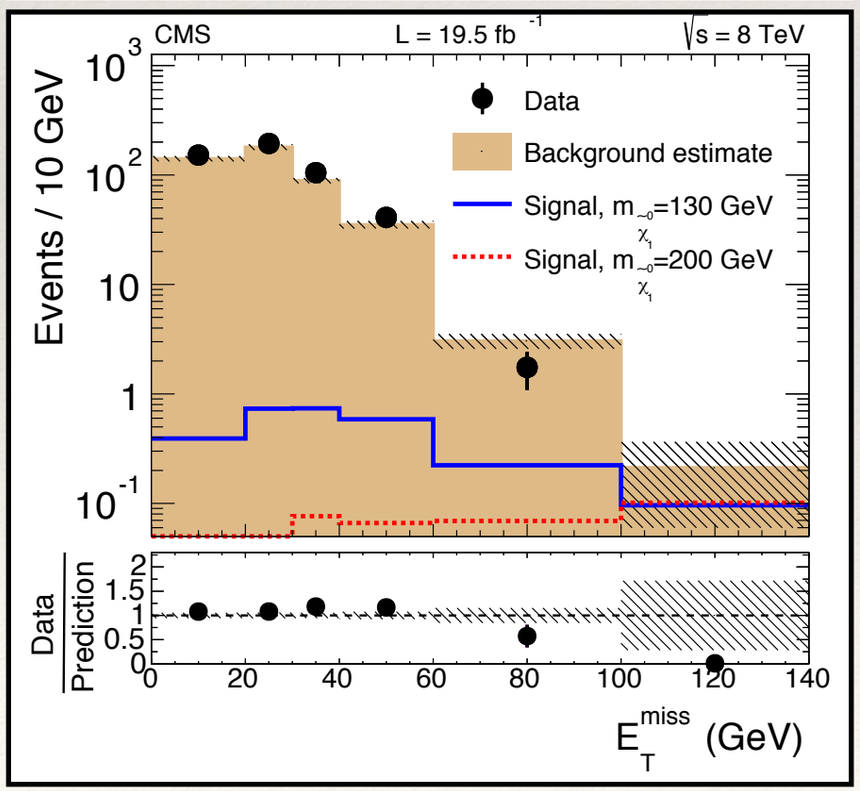
Electroweak SUSY Searches (hZ/W → γγ2j)

CMS-SUS-14-002, PRD 90, 092007 (2014)



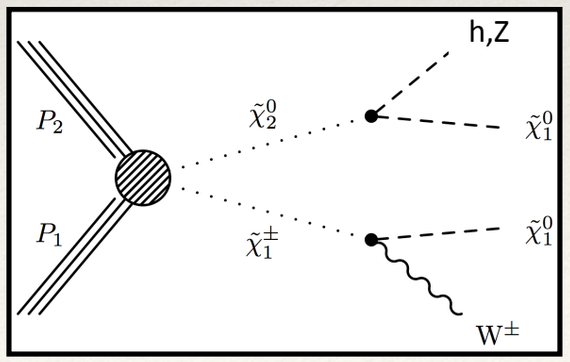
Search for higgs + V(Z,W) production

- **Reconstruct higgs through: h → γγ decay**
- **Reconstruct V through hadronic decay:**
  m_{jj} ∋ [70-110] GeV
- **Discriminating variable E^{miss}_T**



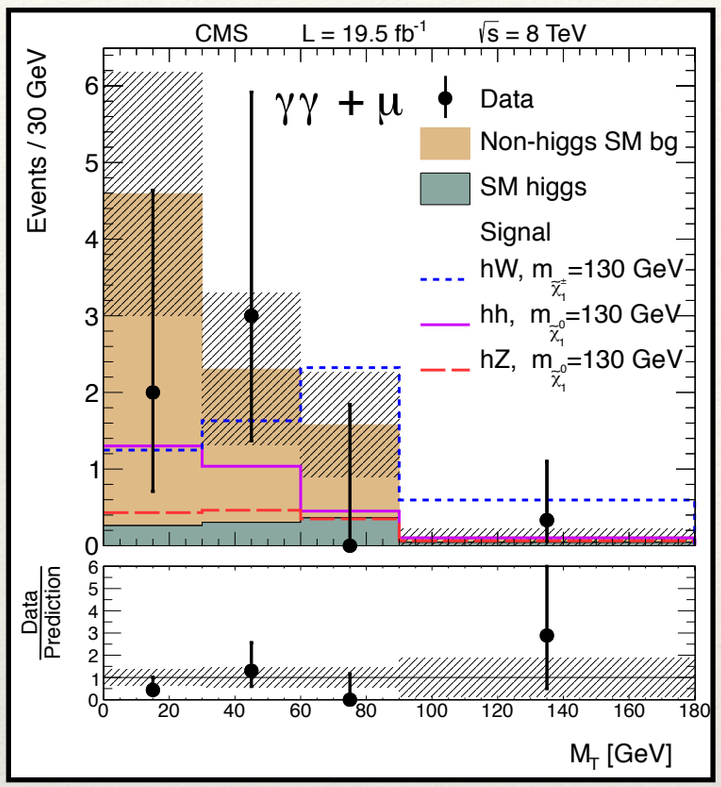
- *Background prediction by extrapolating from $m_{\gamma\gamma}$ sidebands.*

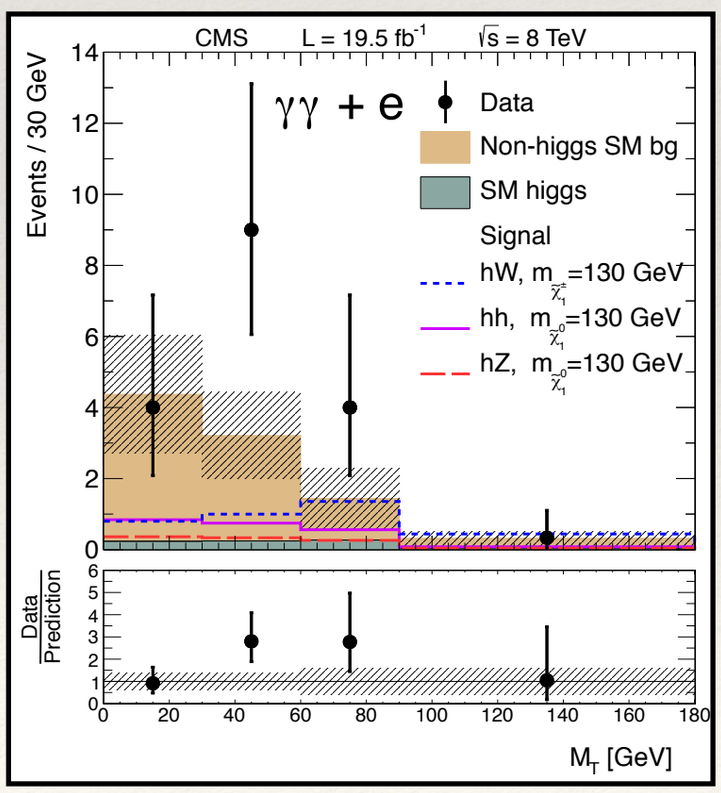
No significant excess observed



SM-Higgs background from MC: 30% uncertainty

Electroweak SUSY Searches (h (h,V) → γγleptons)





CMS-SUS-14-002, PRD 90, 092007 (2014)

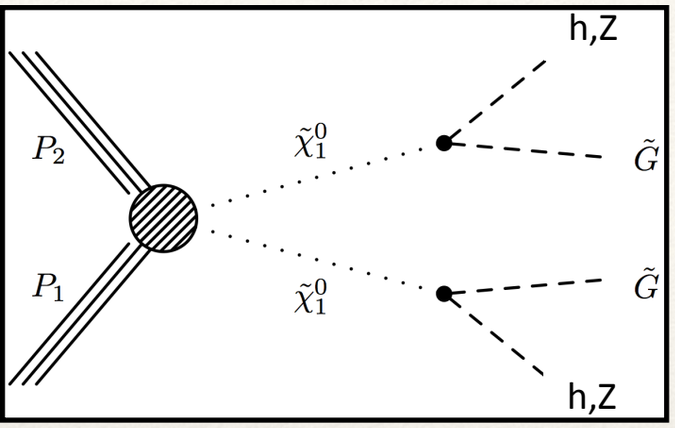
Search for higgs + (h,V) production

- **Reconstruct higgs through: h → γγ decay**
- **Tag second boson by requiring at least one (e/μ)**
- **At least one electron, at least one muon**
- ***Discriminating variable: transverse mass (M_T)***
- ***Background prediction by extrapolating from $m_{\gamma\gamma}$ sidebands.***

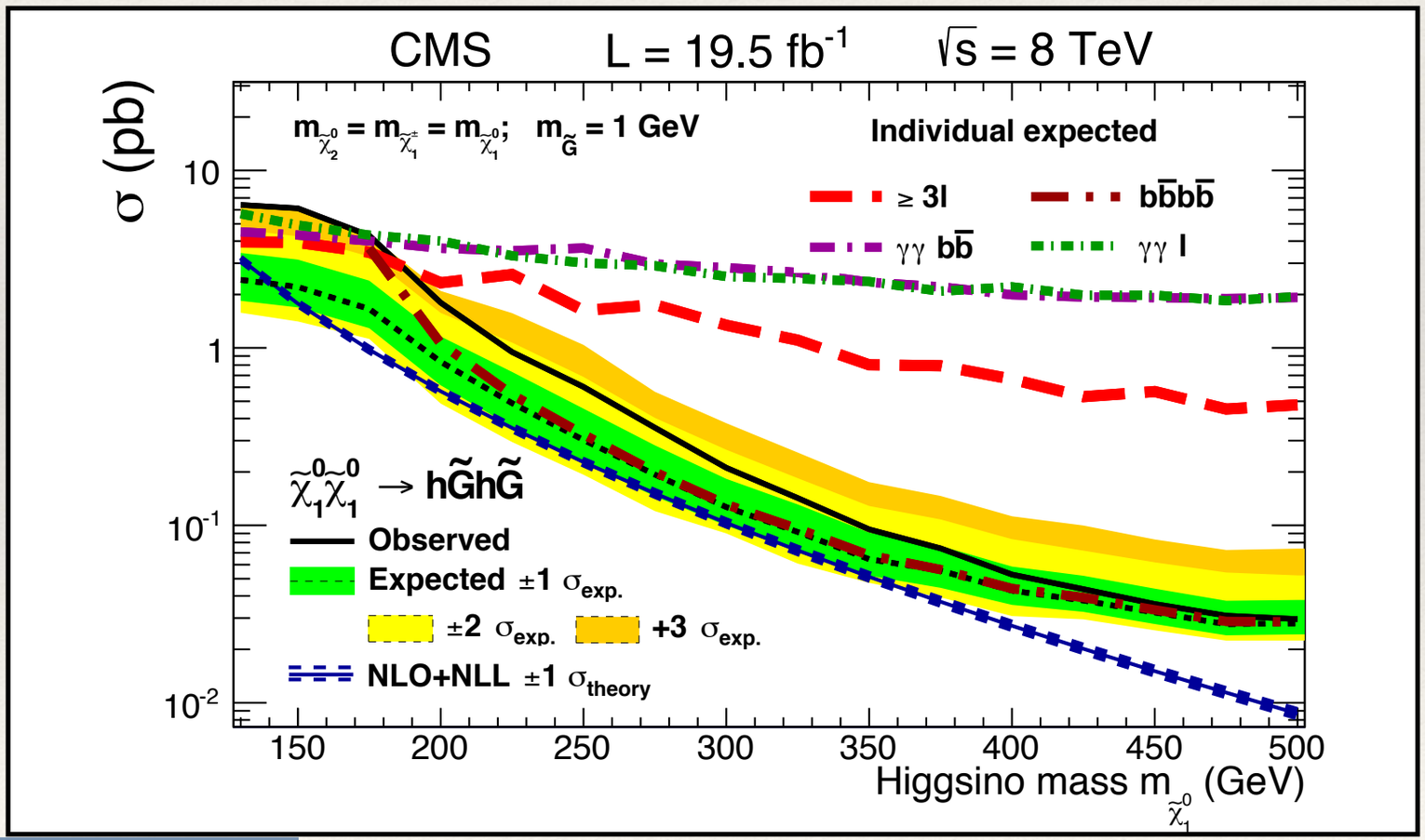
Largest excess observed is 2.1σ in electron sample

SM-Higgs background from MC: 30% uncertainty

Electroweak SUSY Searches



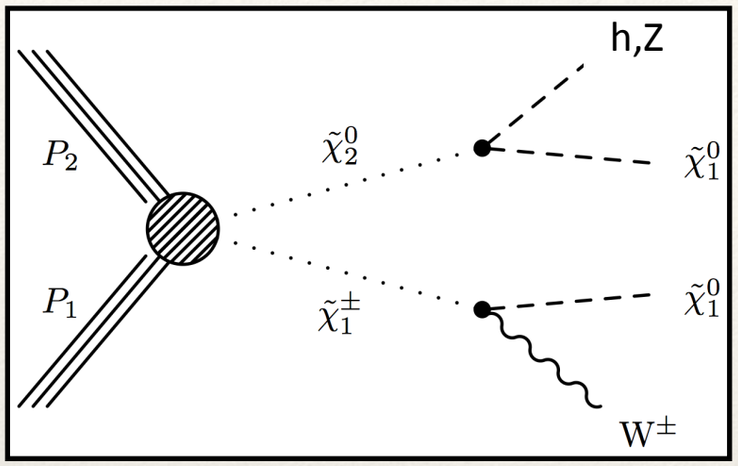
- **Set limits for electroweak GMSB hh production**
  - **hh →γ γbb**
  - **hh →γ γ + lepton**
- ***Expected sensitivity could rule out neutralino at 150 GeV, but observation does not.***



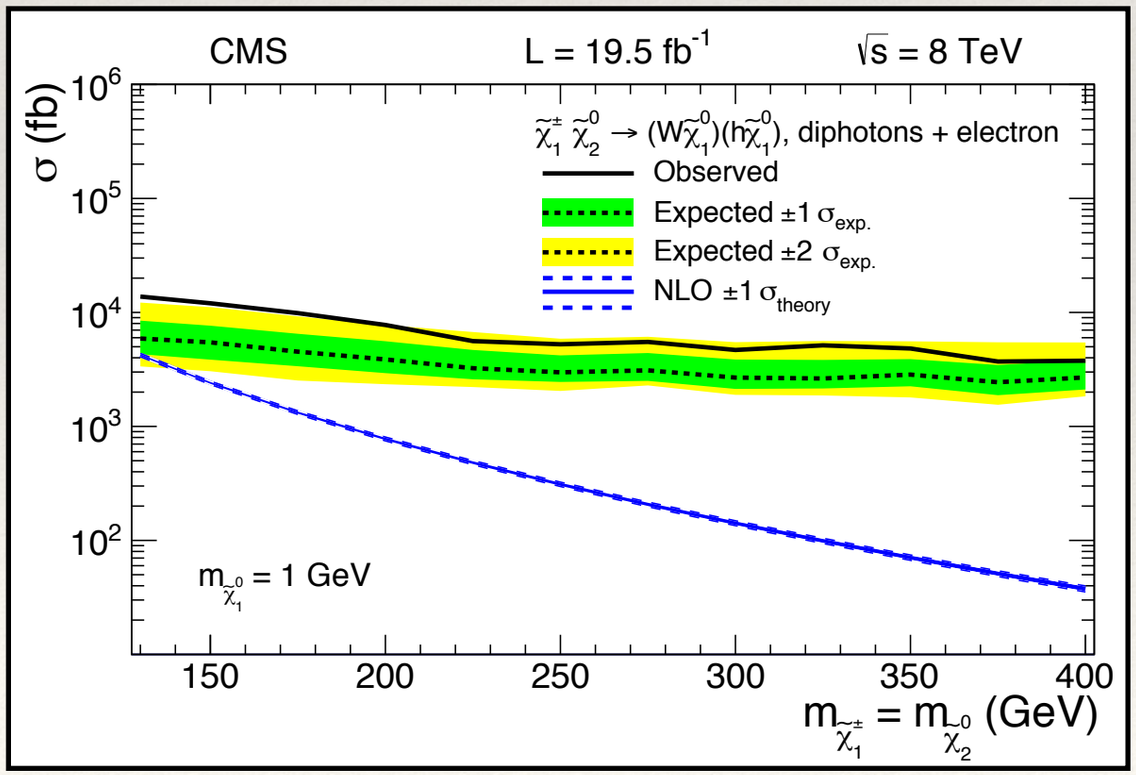
CMS-SUS-14-002, PRD 90, 092007 (2014)

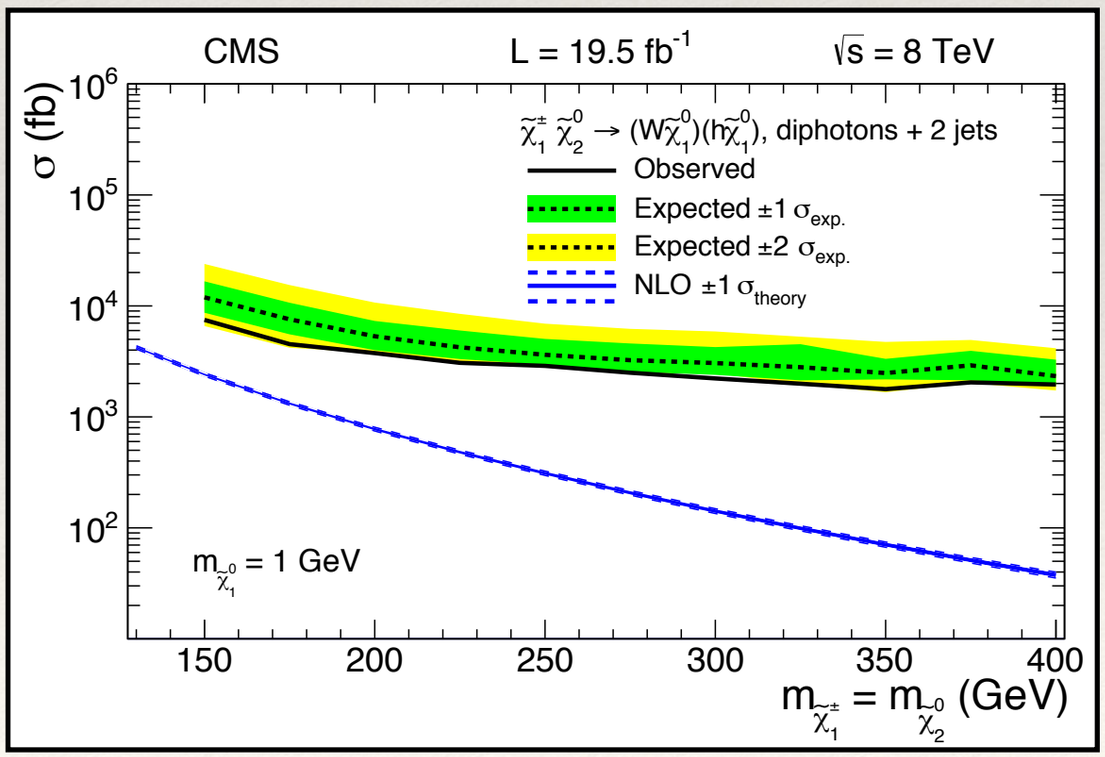
Electroweak SUSY Searches

CMS-SUS-14-002, PRD 90, 092007 (2014)

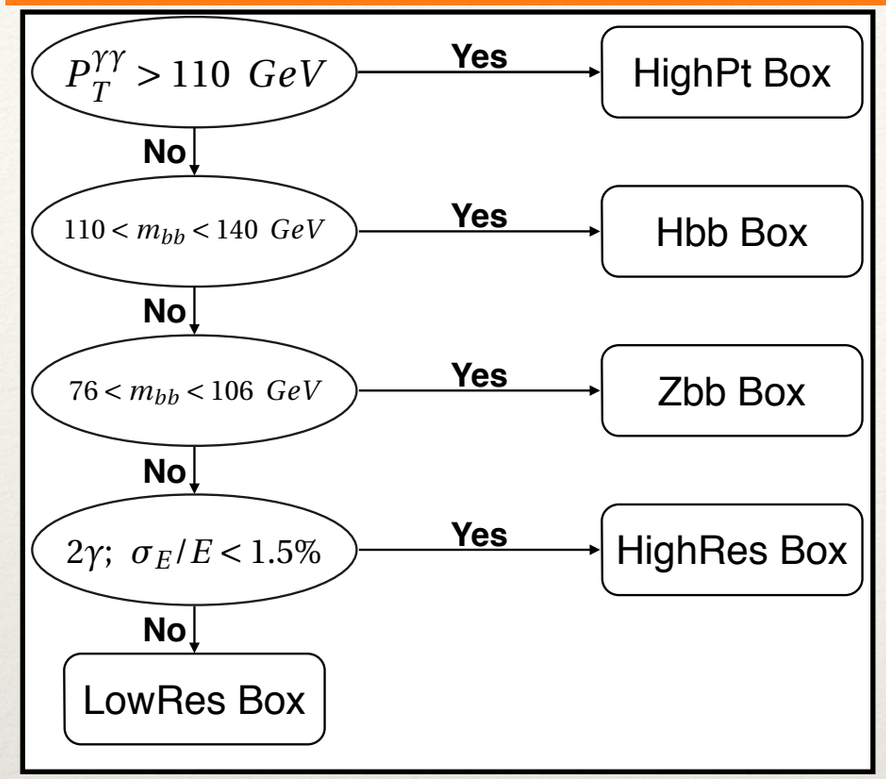


- **Set limits for electroweak *hW production***
  - **hh →γ γ + 2jets**
  - **hh →γ γ + leptons**
- **Current sensitivity from combination of channels is close to theoretical cross section at 130 GeV**

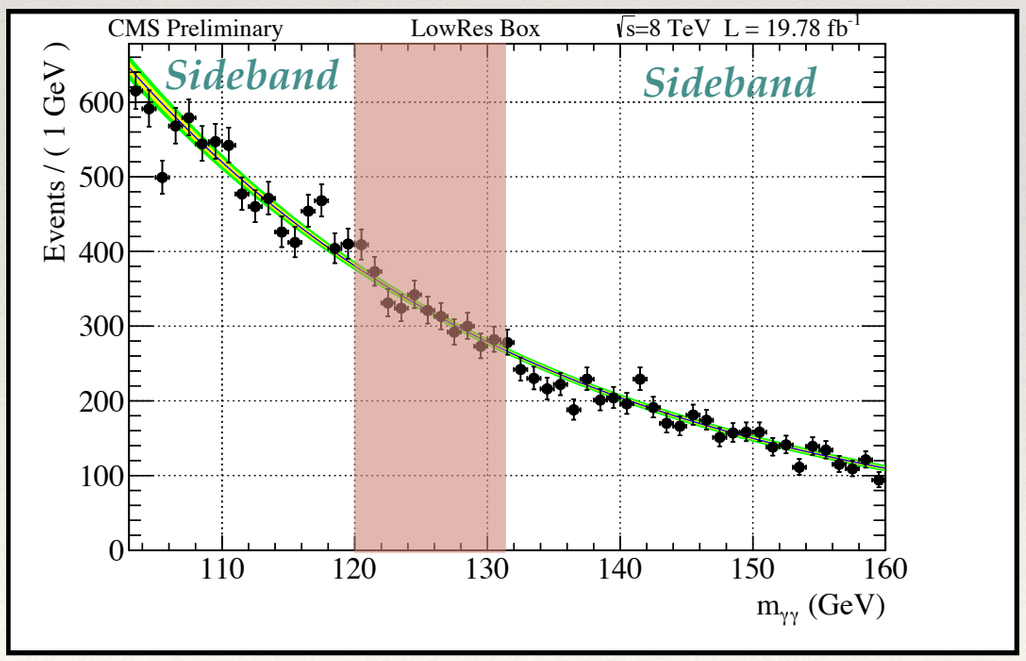




Inclusive Higgs-aware Search



Analysis Event Category Workflow



CMS-SUS-14-017: New Result

NEW!

Inclusive Search for SUSY with Higgs

- **Selection:**
  - **Tag higgs using: h → γγ**
  - **Categorize using higgs P_T and photon resolution**
- **Discriminating variables: M_R and R^2**

- ***Background prediction by extrapolating from $m_{\gamma\gamma}$ sidebands.***

$m_{\gamma\gamma} \ni$ [{103-118}, {133-163}] GeV

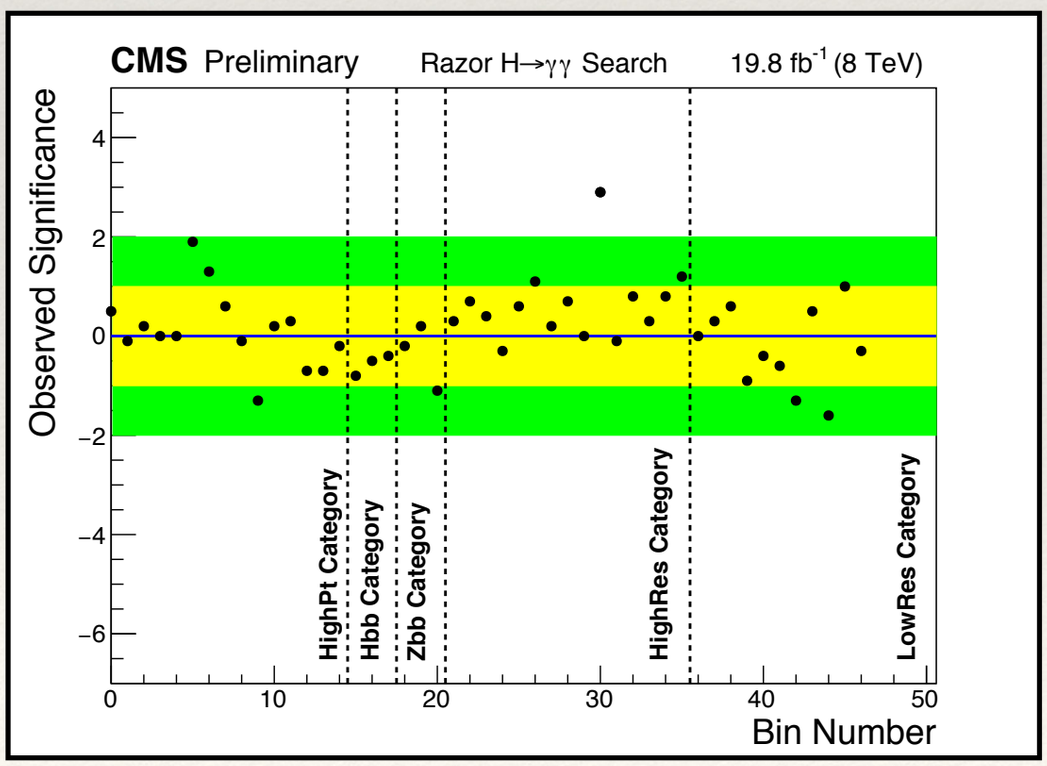
Inclusive Higgs-aware Search

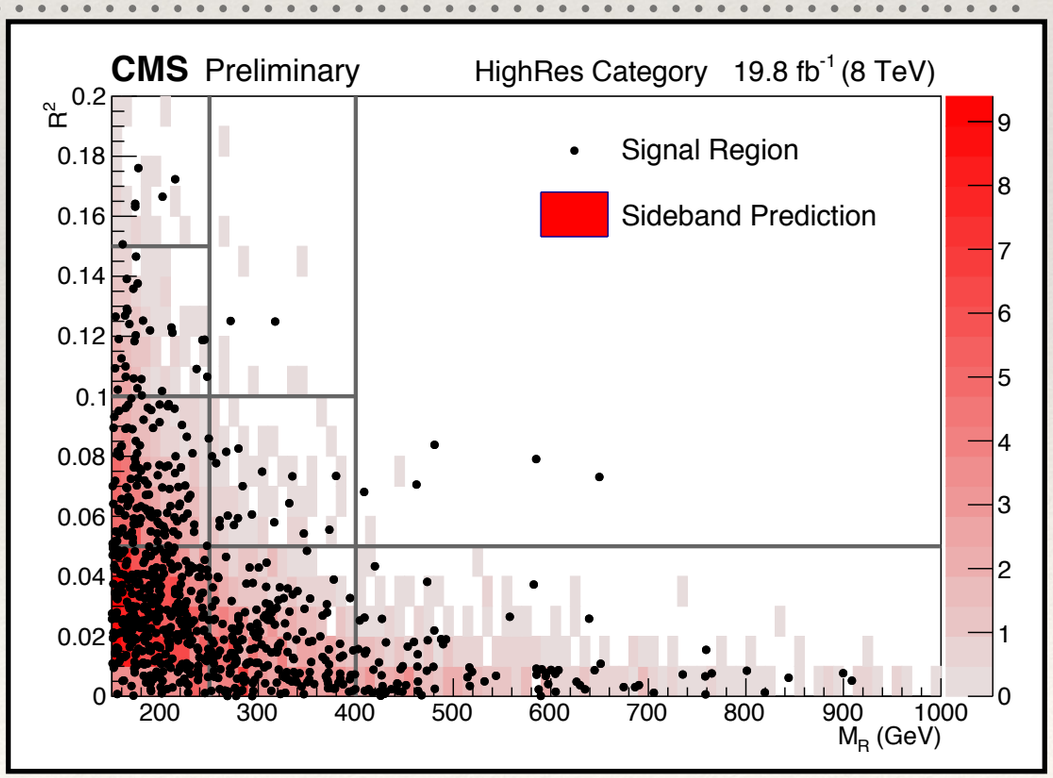
HighRes Event Category Results

M_R region	R^2 region	observed events	expected background	p-value	significance (σ)
150 - 250	0.00 - 0.05	363	$357.6^{+9.6}_{-9.4}$(syst.)	0.40	0.3
150 - 250	0.05 - 0.10	149	$139.4^{+5.6}_{-5.4}$(syst.)	0.23	0.7
150 - 250	0.10 - 0.15	35	$32.5^{+3.4}_{-3.1}$(syst.)	0.34	0.4
150 - 250	0.15 - 1.00	7	$8.0^{+1.7}_{-1.4}$(syst.)	0.40	-0.3
250 - 400	0.00 - 0.05	218	$207.9^{+7.0}_{-6.8}$(syst.)	0.27	0.6
250 - 400	0.05 - 0.10	20	$14.7^{+2.5}_{-2.1}$(syst.)	0.13	1.1
250 - 400	0.10 - 1.00	3	$2.7^{+0.8}_{-0.6}$(syst.)	0.43	0.2
400 - 1400	0.00 - 0.05	109	$101.6^{+5.0}_{-4.8}$(syst.)	0.26	0.7
400 - 1400	0.05 - 1.00	5	$0.5^{+0.4}_{-0.2}$(syst.)	0.002	**2.9**
1400 - 3000	0.00 - 1.00	0	$0.9^{+0.5}_{-0.3}$(syst.)	0.44	-0.1

CMS-SUS-14-017:
New Result

excess is 1.6 σ after look elsewhere effect





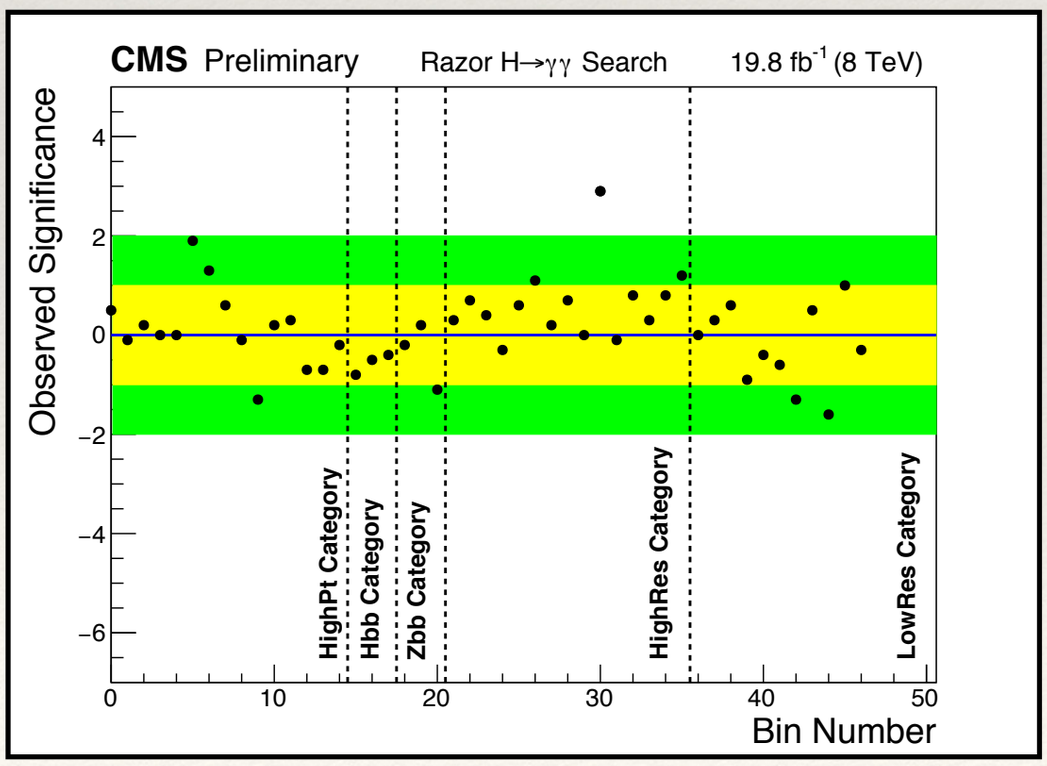
Inclusive Higgs-aware Search

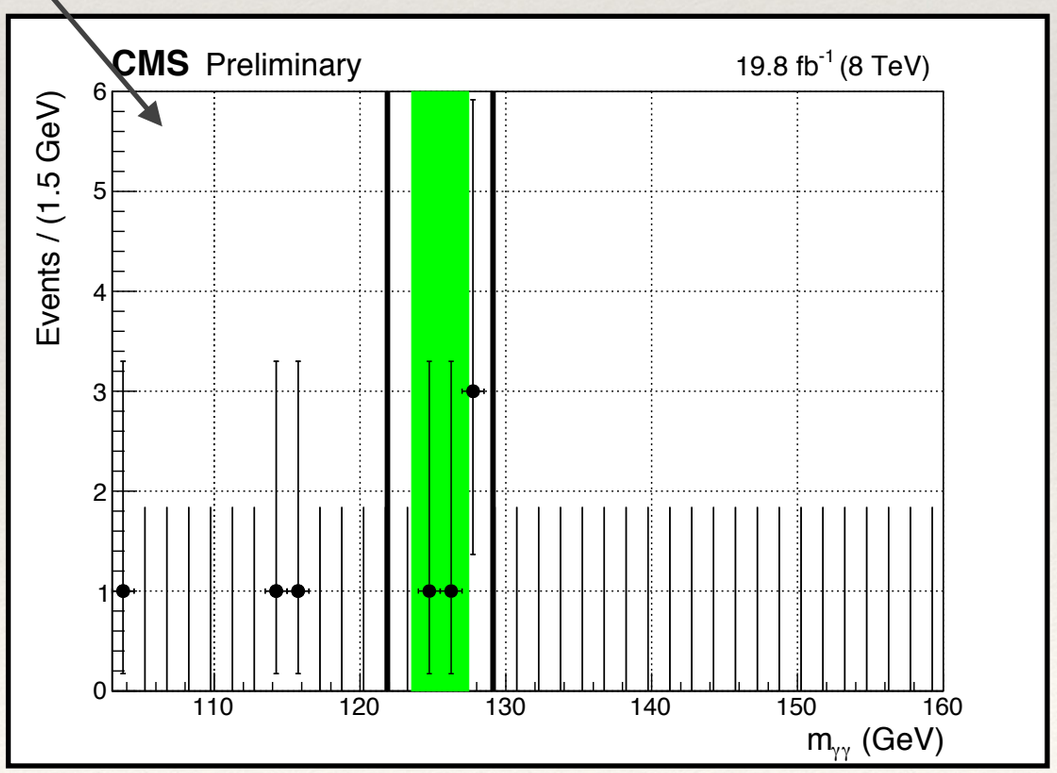
HighRes Event Category Results

M_R region	R^2 region	observed events	expected background	p-value	significance (σ)
150 - 250	0.00 - 0.05	363	$357.6^{+9.6}_{-9.4}$(syst.)	0.40	0.3
150 - 250	0.05 - 0.10	149	$139.4^{+5.6}_{-5.4}$(syst.)	0.23	0.7
150 - 250	0.10 - 0.15	35	$32.5^{+3.4}_{-3.1}$(syst.)	0.34	0.4
150 - 250	0.15 - 1.00	7	$8.0^{+1.7}_{-1.4}$(syst.)	0.40	-0.3
250 - 400	0.00 - 0.05	218	$207.9^{+7.0}_{-6.8}$(syst.)	0.27	0.6
250 - 400	0.05 - 0.10	20	$14.7^{+2.5}_{-2.1}$(syst.)	0.13	1.1
250 - 400	0.10 - 1.00	3	$2.7^{+0.8}_{-0.6}$(syst.)	0.43	0.2
400 - 1400	0.00 - 0.05	109	$101.6^{+5.0}_{-4.8}$(syst.)	0.26	0.7
400 - 1400	0.05 - 1.00	5	$0.5^{+0.4}_{-0.2}$(syst.)	0.002	**2.9**
1400 - 3000	0.00 - 1.00	0	$0.9^{+0.5}_{-0.3}$(syst.)	0.44	-0.1

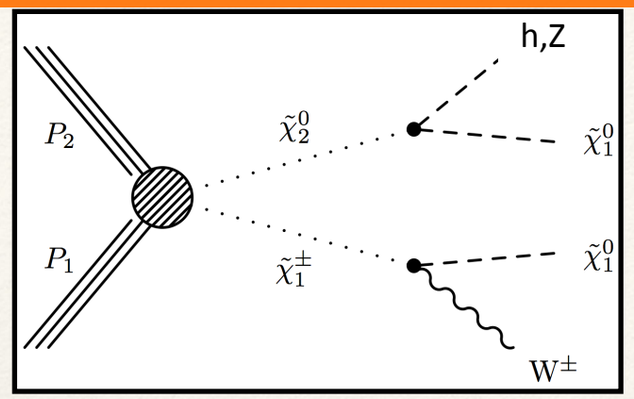
CMS-SUS-14-017:
New Result

excess is 1.6 σ after look elsewhere effect

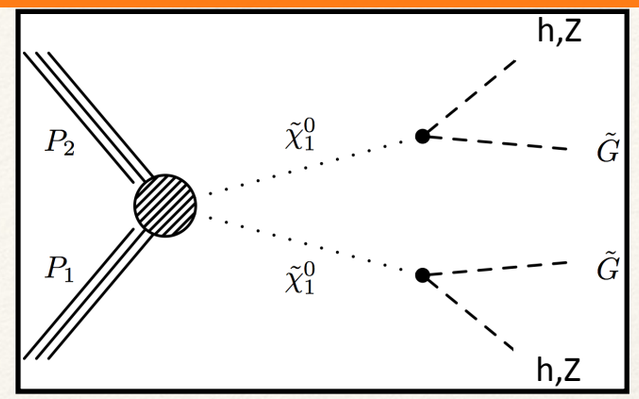




Inclusive Higgs-aware Search

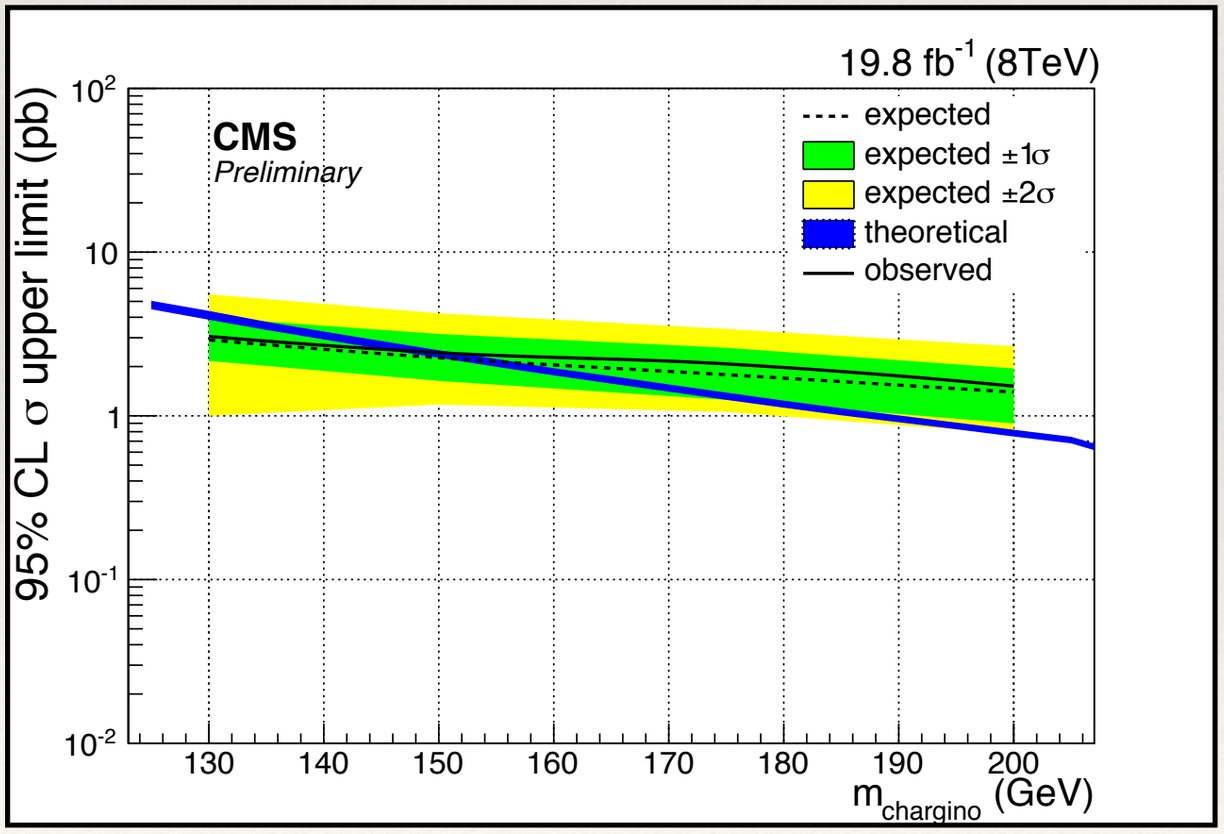


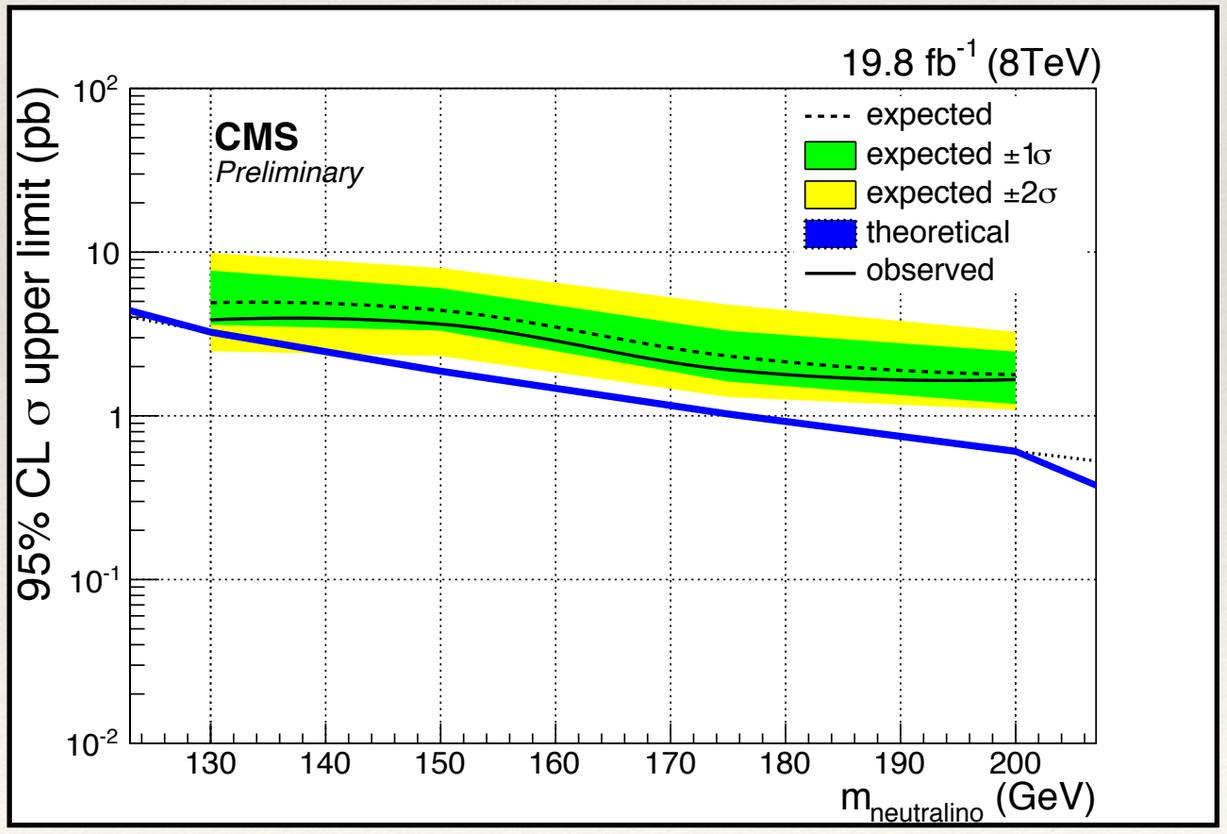
CMS-SUS-14-017:
New Result



- **hW electroweak production**
- *Exclude a 130-150 GeV neutralino/ chargino*

- **hh electroweak production**
- *Sensitivity close to exclude a 130 GeV neutralino*

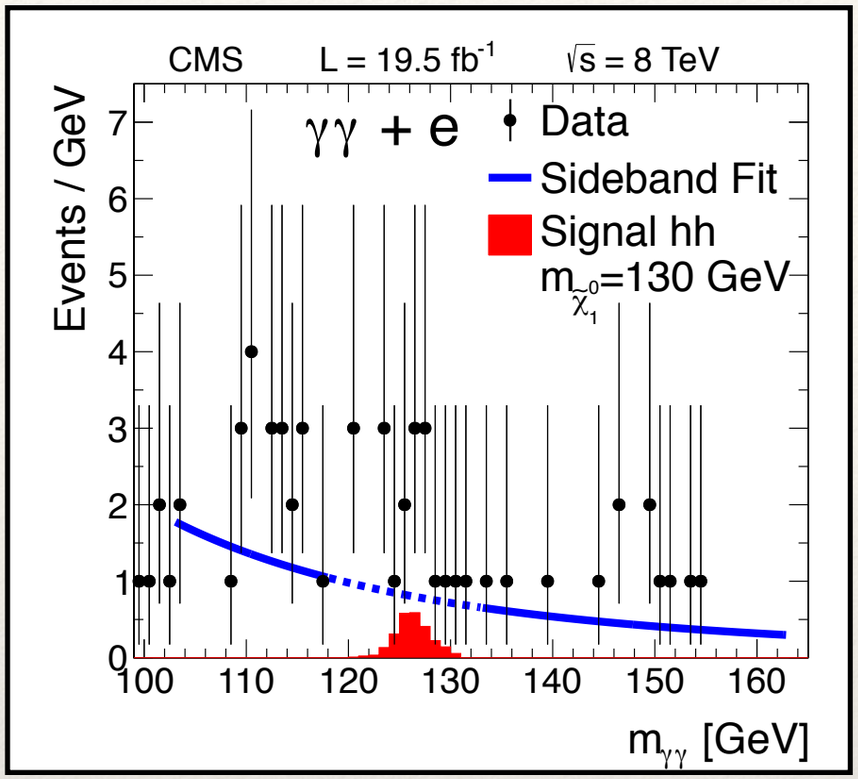


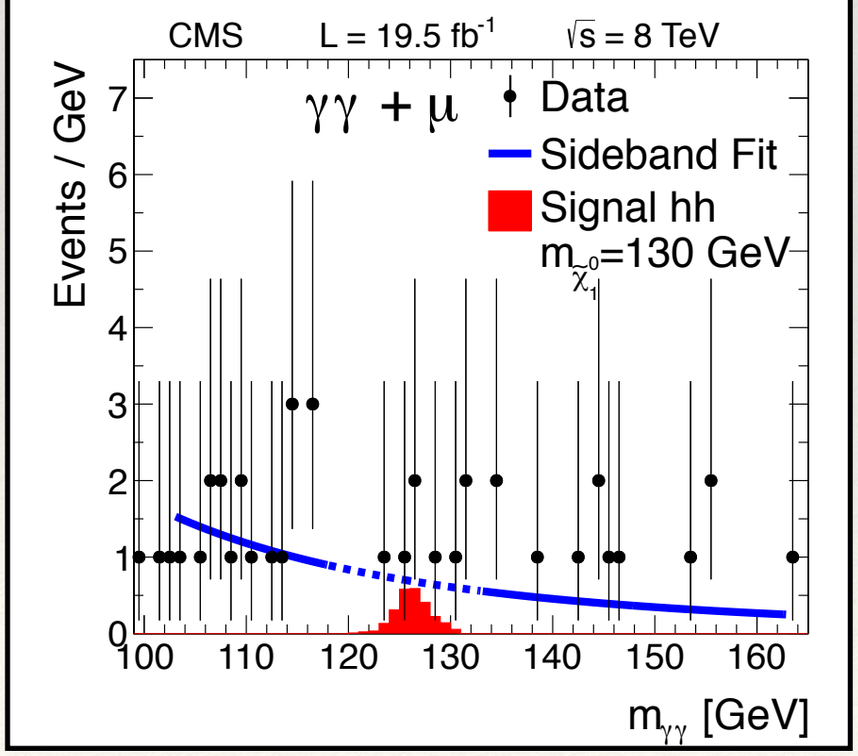


Summary

- **CMS searches for GMSB SUSY gluino/squark production**
  - *single and diphoton final state, no excesses found*
  - *Exclude gluino at 1.0 TeV and squark at 0.8 TeV (wino case)*
  - *Exclude gluino at 1.5 TeV and squark at 1.4 TeV (bino case)*
- **CMS searches for GMSB SUSY EW production**
  - *Use SM h (h→γγ) as a tool to look for SUSY*
  - *New analyses improve sensitivity to hh, hW electroweak production. hW, chargino/neutralino excluded at 150 GeV*
- **New higgs-aware search: does not depend on a particular SUSY model. Enhances possible discovery.**
- **Interesting results. Stay tuned for 13 TeV photon updates**

Backups





CMS-SUS-14-002, PRD 90, 092007 (2014)

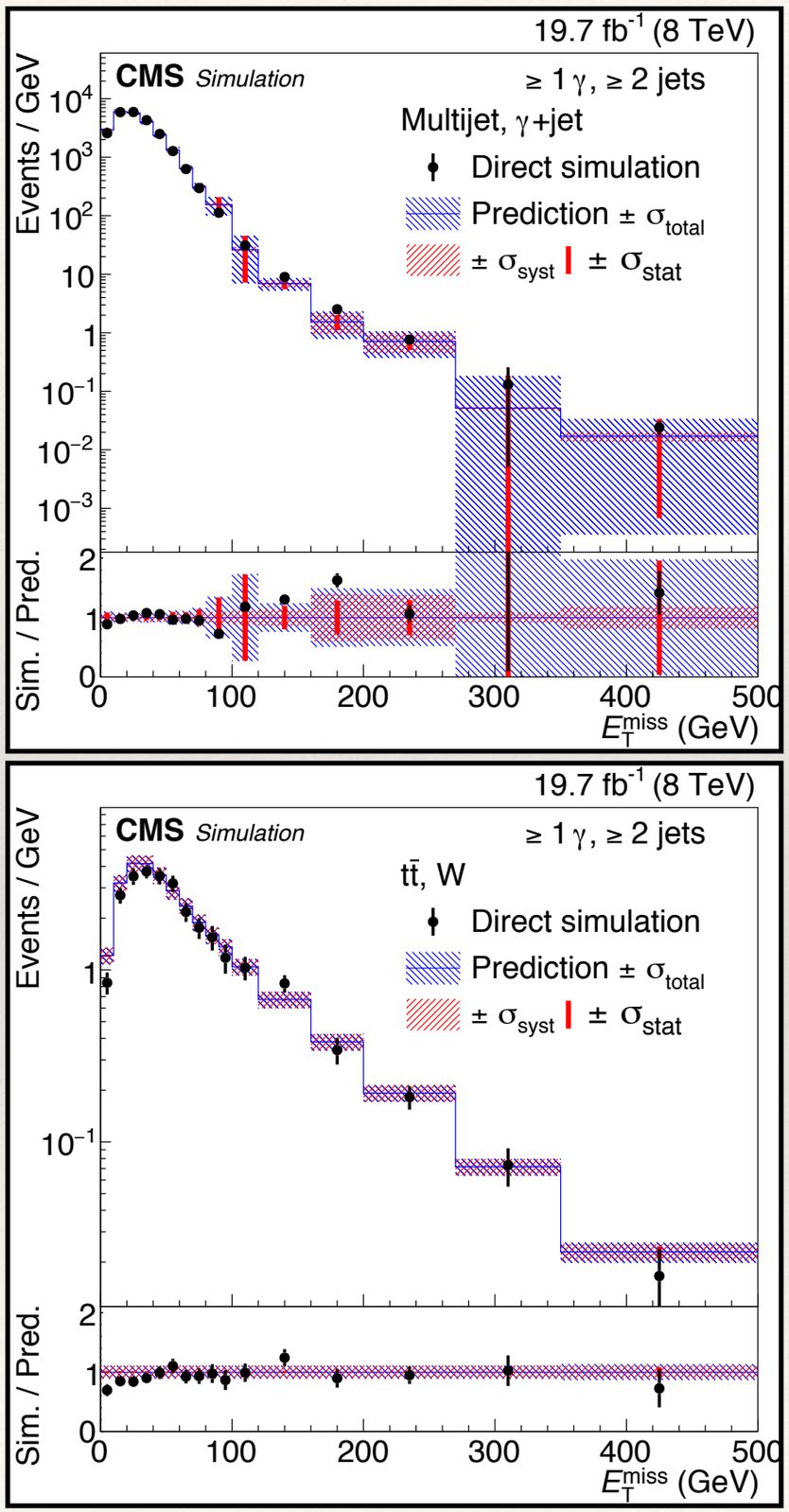
Search for higgs + (h,V) production

- Apply standard photon selection
- Reconstruct one higgs candidate by its $\gamma\gamma$ decay
  - $m_{\gamma\gamma} \ni [103\text{-}163]$ GeV
- Tag second boson by requiring at least one (e/μ)
  - Isolated Leptons, $P_T > 15$ GeV, $|\eta| < 2.4$
  - $\Delta R(\gamma_{(1,2)}, \text{lepton}) > 0.3$
  - $m_{e\gamma} \notin [86\text{-}96]$ GeV
- Two search samples:
  - At least one electron, at least one muon
- *Look for excess in the transverse mass M_T distribution*
- *Fit $m_{\gamma\gamma}$ in sidebands. Use fit result to scale the M_T sideband distribution to the expected signal region.*

2.1 standard deviations excess in electron sample. cross checks suggest consistent with background fluctuation

SM-Higgs background from MC: 30% uncertainty

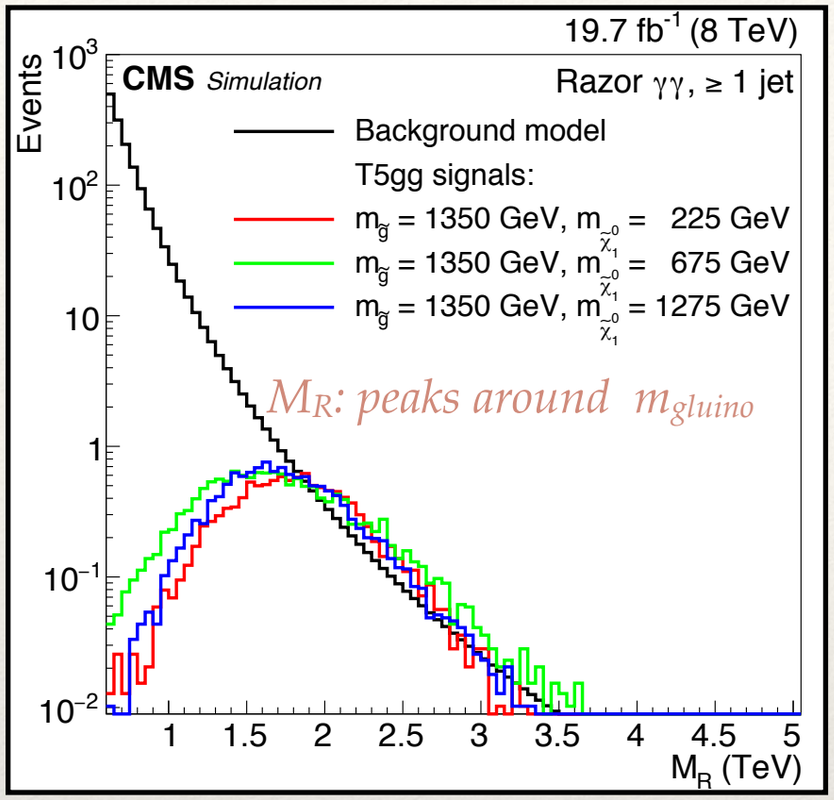
Single Photon Analysis

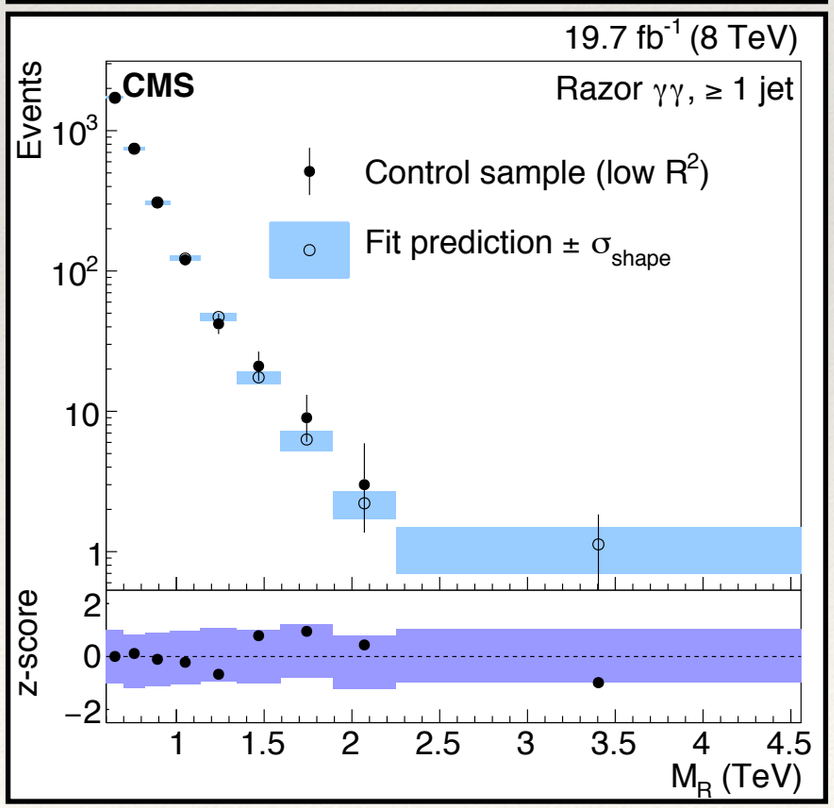


CMS-SUS-14-004, PRD 1507.02898

- **Selection:**
  - **At least one photon (γ): $P^*_T > 110$ GeV**
  - **At least two jets: $P_T > 30$ GeV, $|\eta| < 2.5$, $\Delta R(\gamma, j_i) > 0.3$**
  - **$H^*_T > 500$ GeV (including γ)**
- **SM backgrounds**
  - **QCD multijet events: mismeasured E^{miss}_T + fakes**
  - **QCD multijet + γ: mismeasured E^{miss}_T**
  - **W+jets and tt + jets (EW): real E^{miss}_T, e →γ**
  - **γW+jets, γZ+jets, γtt + jets**
- **Discriminating variable**
  - **$E^{miss}_T > 100$ GeV, 6 bin categories**
- **Background estimation**
  - **Use a γ^{loose} (relax isolation) control sample. Obtain correction factors for E^{miss}_T . *Predict Multijet and γ+jet***
  - **Use a γ^{pixel} (pixel seed match) control sample. Predict EW scaling E^{miss}_T distribution by $f_{e\to\gamma}$**

Double Photon Analysis





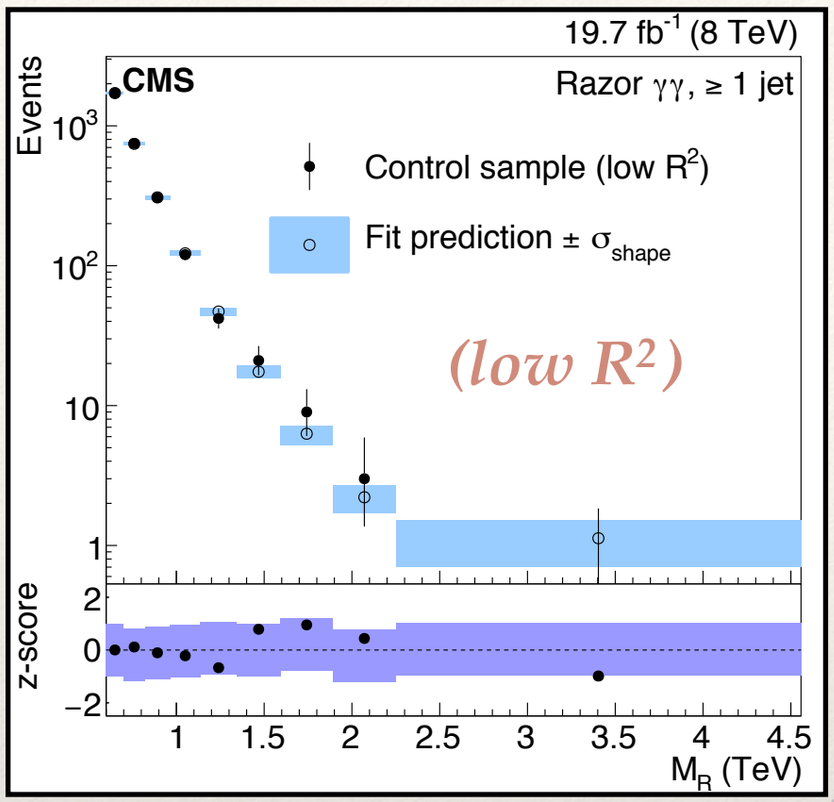
CMS-SUS-14-004, PRD 1507.02898

- **Selection:**
  - At least two photons (γ): $P^{lead}_T > 30$, $P^{sublead}_T > 22$ GeV
  - At least one jet: $P_T > 40$ GeV, $|\eta| < 2.5$, $\Delta R(\gamma_{(1,2)}, j_i) > 0.5$
- SM backgrounds
  - QCD multijet events: mismeasured E^{miss}_T + fakes
  - QCD multijet + γ: mismeasured E^{miss}_T *(dominant)*
  - W+jets and tt + jets (EW): real E^{miss}_T, e →γ *(negligible)*
- Discriminating variable
  - Razor variables: M_R *(mass scale)* and R^2 *(energy imbalance)*
- Background estimation
  - Define control region $M_R > 600$ GeV && $0.01 < R^2 < 0.02$.

    Fit M_R with $P(M_R) \propto e^{-k(M_R - M_R^0)^{\frac{1}{n}}}$
  - Use fit shape normalize to the total number of events as background prediction in signal region

Fit to control sample:
bottom panel z-score (number of Normal standard deviation)

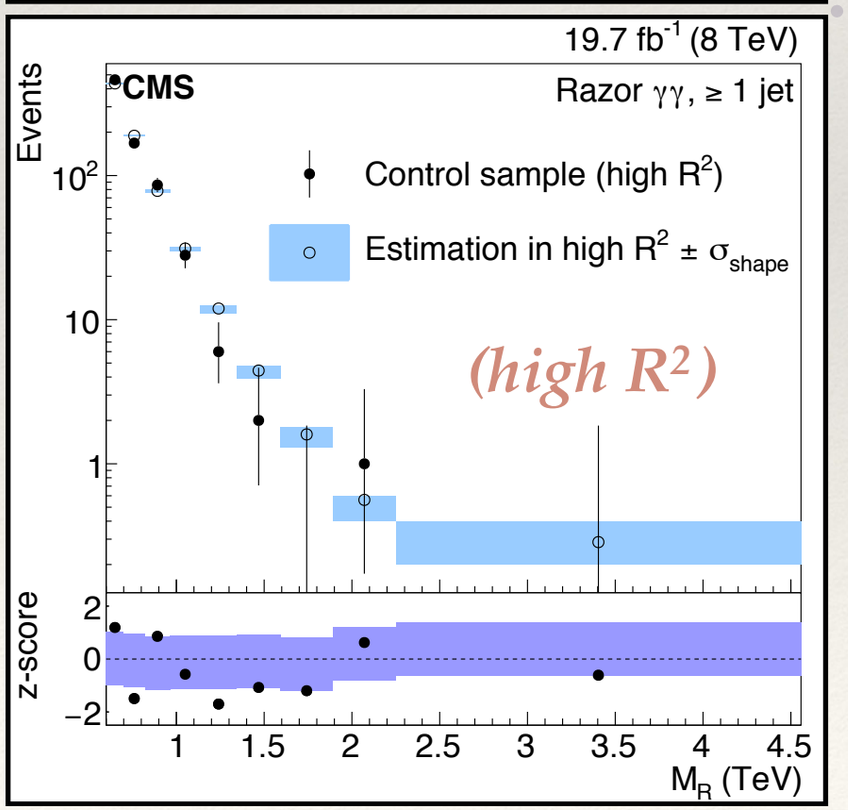
Double Photon Analysis



Background Prediction

- **Define control region M_R > 600 GeV && 0.01 < R^2 < 0.02.**
  Fit M_R with $P(M_R) \propto e^{-k(M_R - M_R^0)^{\frac{1}{n}}}$ ***(low R^2)***
- **Normalize to the total yield as background prediction in signal region**

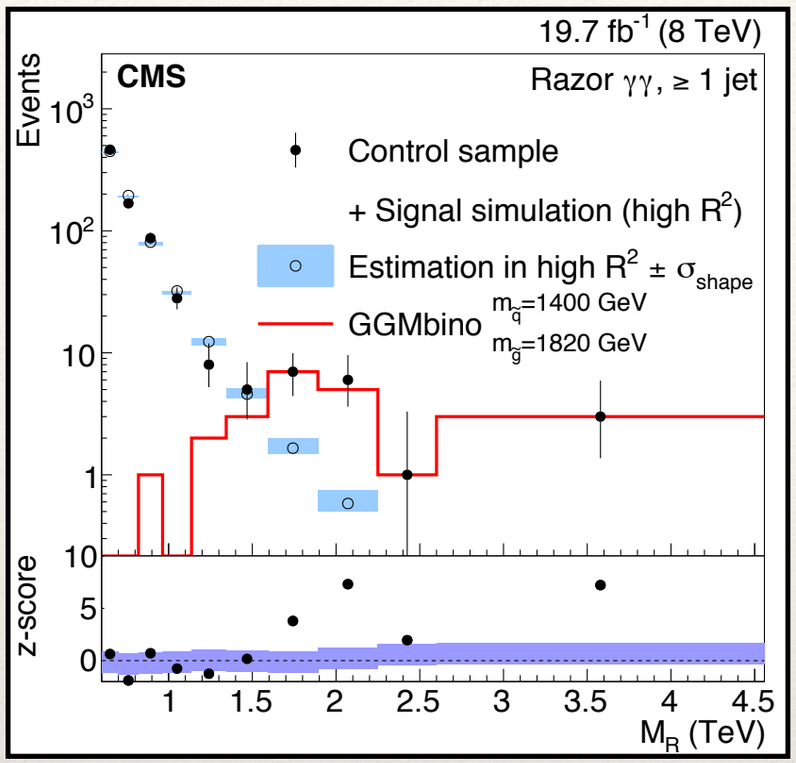
CMS-SUS-14-004, PRD 1507.02898



Background Prediction Validation

- **Search region: M_R > 600 GeV && R^2 > 0.2** ***(high R^2)***
- **Control sample in high R^2 kinematic region with photons failing isolation/cluster shape**
- ***No observed systematic deviation. within one standard deviation***

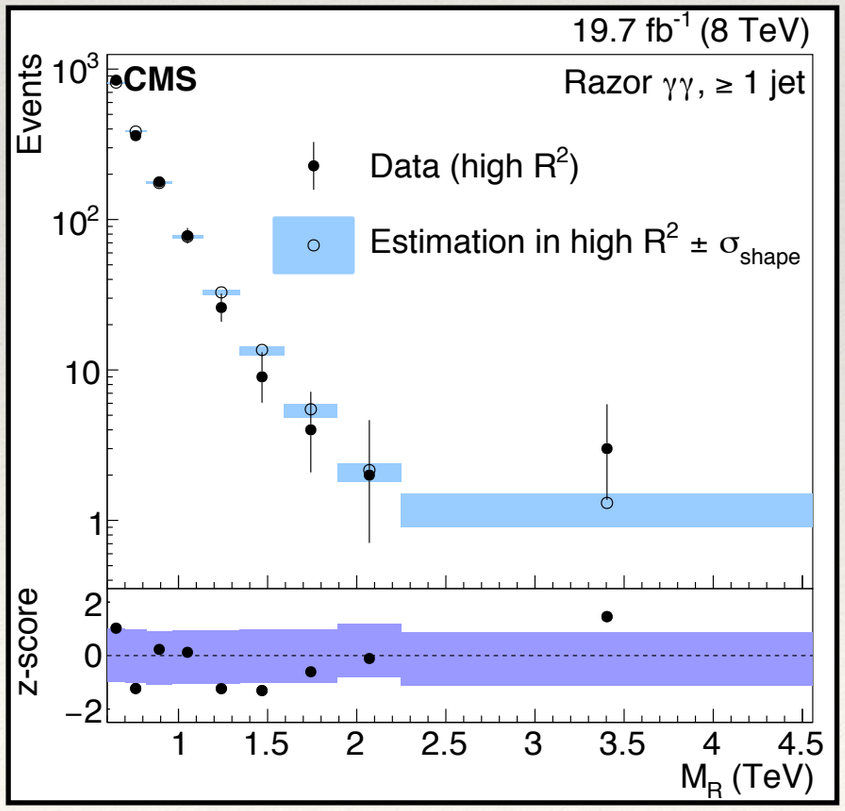
Double Photon Analysis



Signal Injection Test

CMS-SUS-14-004, PRD 1507.02898

- **Inject signal events to the control sample**
  - *$m_{gluino} = 1820$ GeV, $m_{squark} = 1400$ GeV (GGMbino)*
- **Clear excess at $M_R \simeq 2$ TeV. This is how an signal would show up.** *Analysis works as designed*



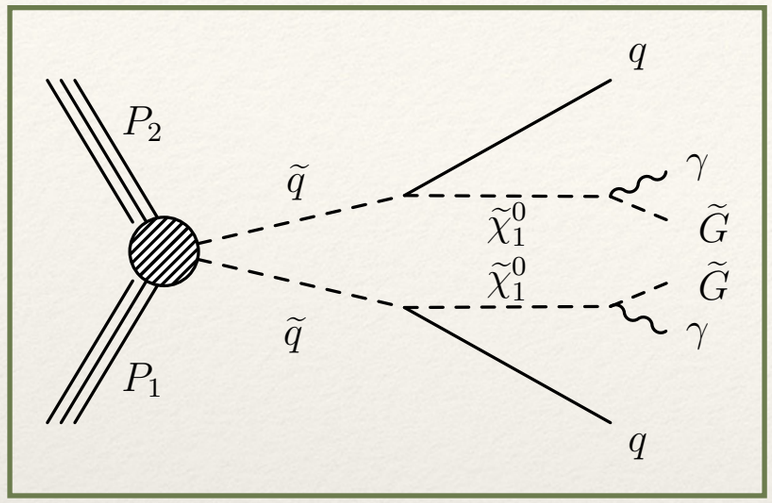
Results

- **Extrapolate fit shape to signal region**
- **Look for excess in $M_R > 600$ GeV**

No excess in any M_R bin.

Double Photon Analysis

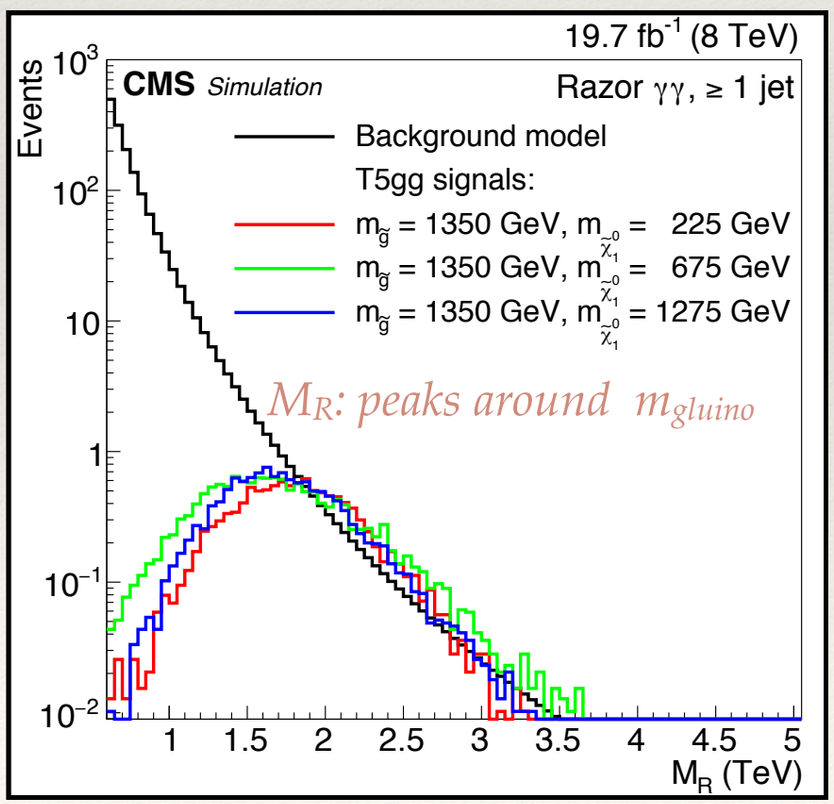
CMS-SUS-14-004, PRD 1507.02898



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

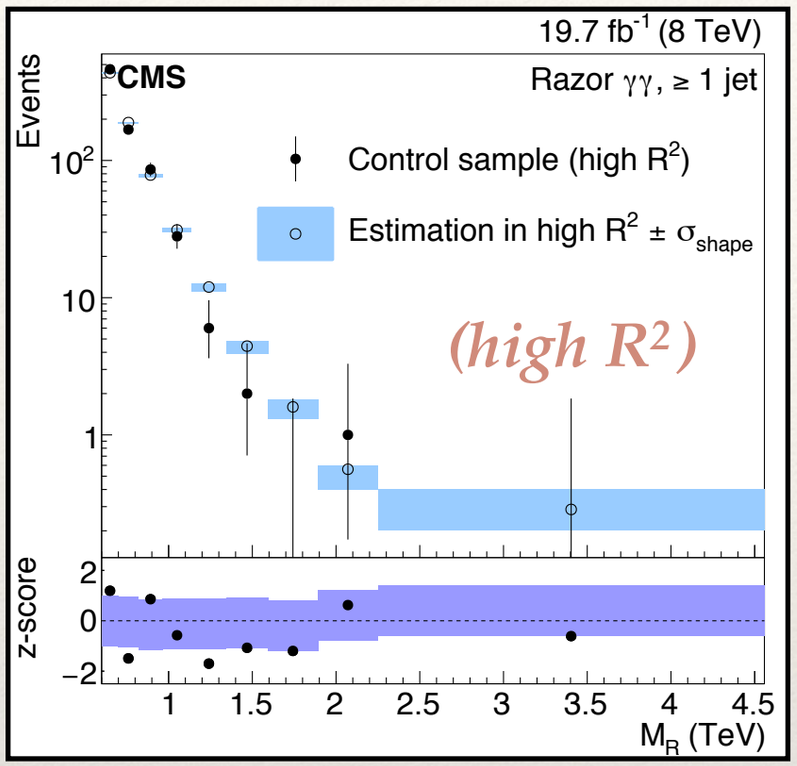
$$\mathrm{R}^2 \equiv \left(\frac{M_{\mathrm{T}}^{\mathrm{R}}}{M_{\mathrm{R}}}\right)^2,$$

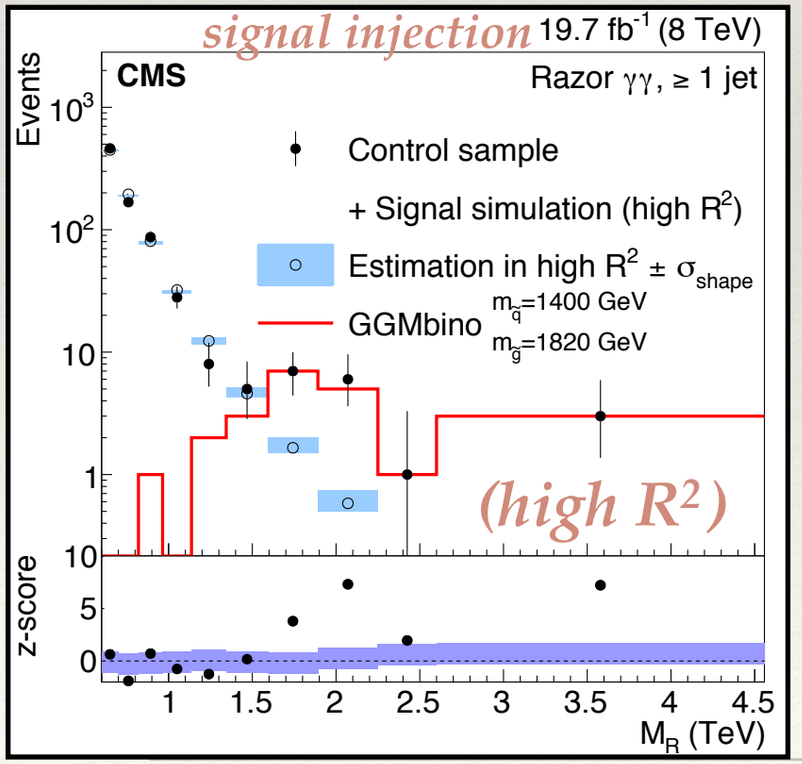
$$M_{\mathrm{T}}^{\mathrm{R}} \equiv \sqrt{\frac{E_{\mathrm{T}}^{\mathrm{miss}}(p_{\mathrm{T}}^{j_1} + p_{\mathrm{T}}^{j_2}) - \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} \cdot (\vec{p}_{\mathrm{T}}^{\,j_1} + \vec{p}_{\mathrm{T}}^{\,j_2})}{2}}.$$



M_R: peaks around m_{gluino}

Double Photon Analysis





- **Search region: $M_R > 600$ GeV && $R^2 > 0.2$** *(high R^2)*
- **Define a control sample in the high R^2 kinematic region with photons failing isolation/cluster shape**

Background Prediction Validation

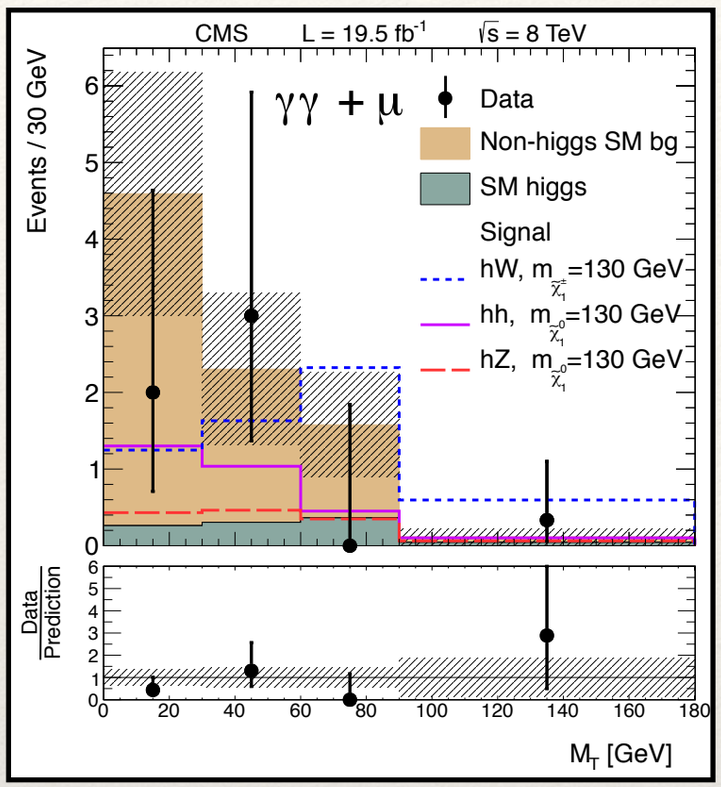
- **Test background prediction technique in this control sample**
- **Normalize obtained fit shape** $P(M_R) \propto e^{-k(M_R - M_R^0)^{\frac{1}{n}}}$ **to observed yield in control sample (high R^2)**
- *No observed systematic deviation. Most deviations are within one standard deviation*

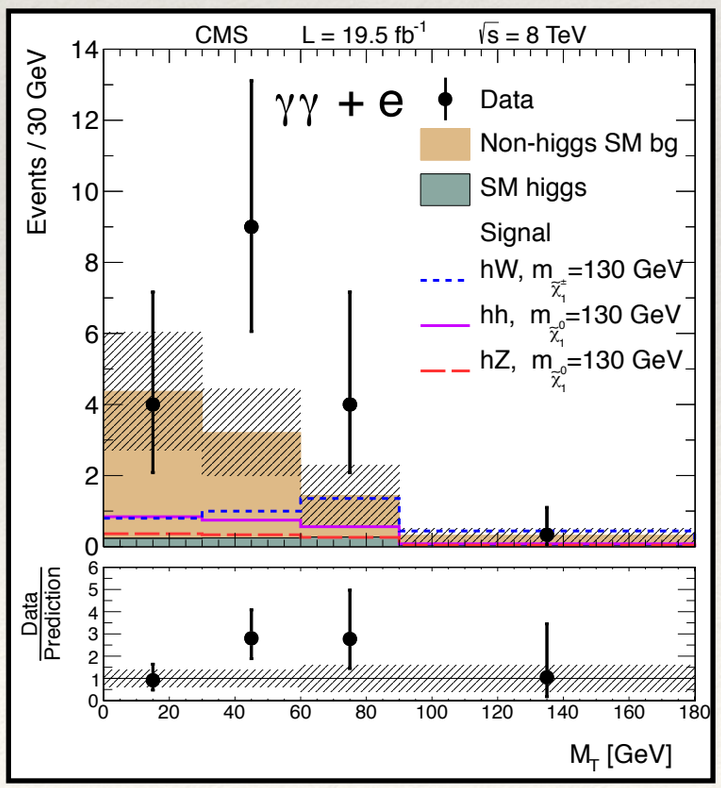
Signal Injection Test

CMS-SUS-14-004, PRD 1507.02898

- **Test analysis sensitivity/behavior**
- **Inject signal events to the control sample data**
  - $m_{gluino} = 1820$ *GeV,* $m_{squark} = 1400$ *GeV (GGMbino)*
- **Use same prediction as in the background prediction validation**
- **Clear excess at $M_R \simeq 2$ TeV. This is how an signal would show up.** *Analysis works as designed*

Electroweak SUSY Searches (h (h,V) → γγleptons)





CMS-SUS-14-002, PRD 90, 092007 (2014)

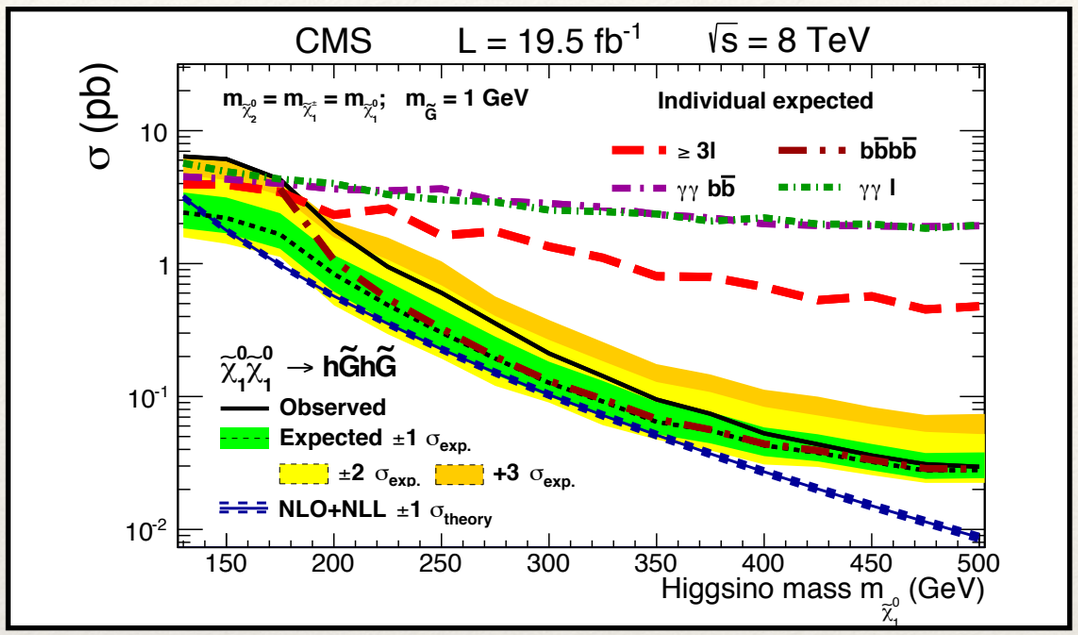
Search for higgs + (h,V) production

- Apply standard photon selection
- Reconstruct higgs through: h → γγ decay
- Tag second boson by requiring at least one (e/μ)
  - Isolated Leptons, $P_T > 15$ GeV, $|\eta| < 2.4$
  - $\Delta R(\gamma_{(1,2)}, \text{lepton}) > 0.3$
  - $m_{e\gamma} \notin [86\text{-}96]$ GeV
- Two search samples:
  - At least one electron, at least one muon
- *Look for excess in the transverse mass M_T distribution*
- *Fit $m_{\gamma\gamma}$ in sidebands. Use fit result to scale the M_T sideband distribution to the expected signal region.*

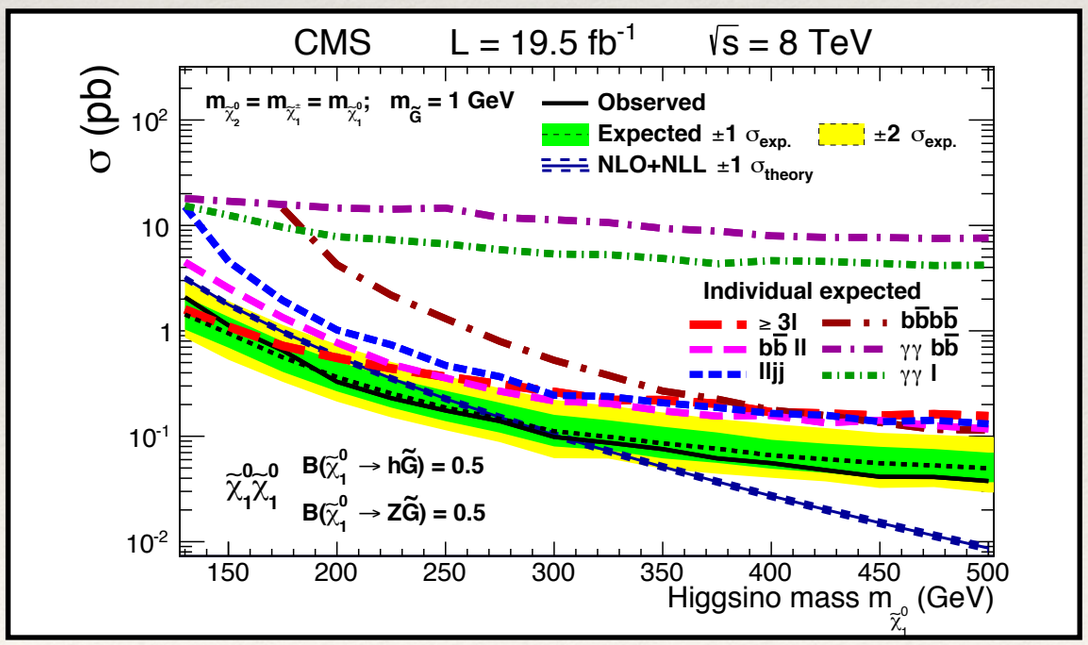
2.1 standard deviations excess in electron sample.
cross checks suggest consistent with background fluctuation

SM-Higgs background from MC: 30% uncertainty

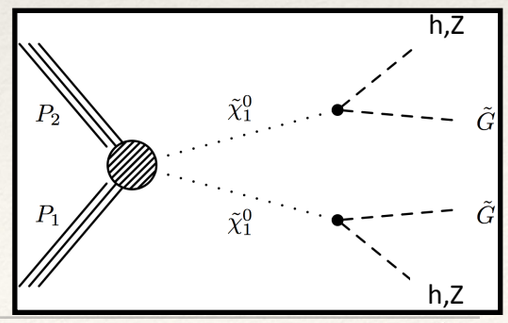
Electroweak SUSY Searches



- Set limits for electroweak GMSB hh production
- hh production In this talk
  - hh →ɣ ɣbb
  - hh →ɣ ɣ + lepton
- Not enough sensitivity to exclude any neutralino mass yet
- Expected sensitivity could rule out a 150 GeV neutralino



- Set limits for electroweak GMSB h h,Z production
- 50% BR to $\chi^1 \rightarrow ZG$
- hh production In this talk
  - hh →ɣ ɣbb
  - hh →ɣ ɣ + lepton
- Combination excludes neutralinos at ~ 290 GeV



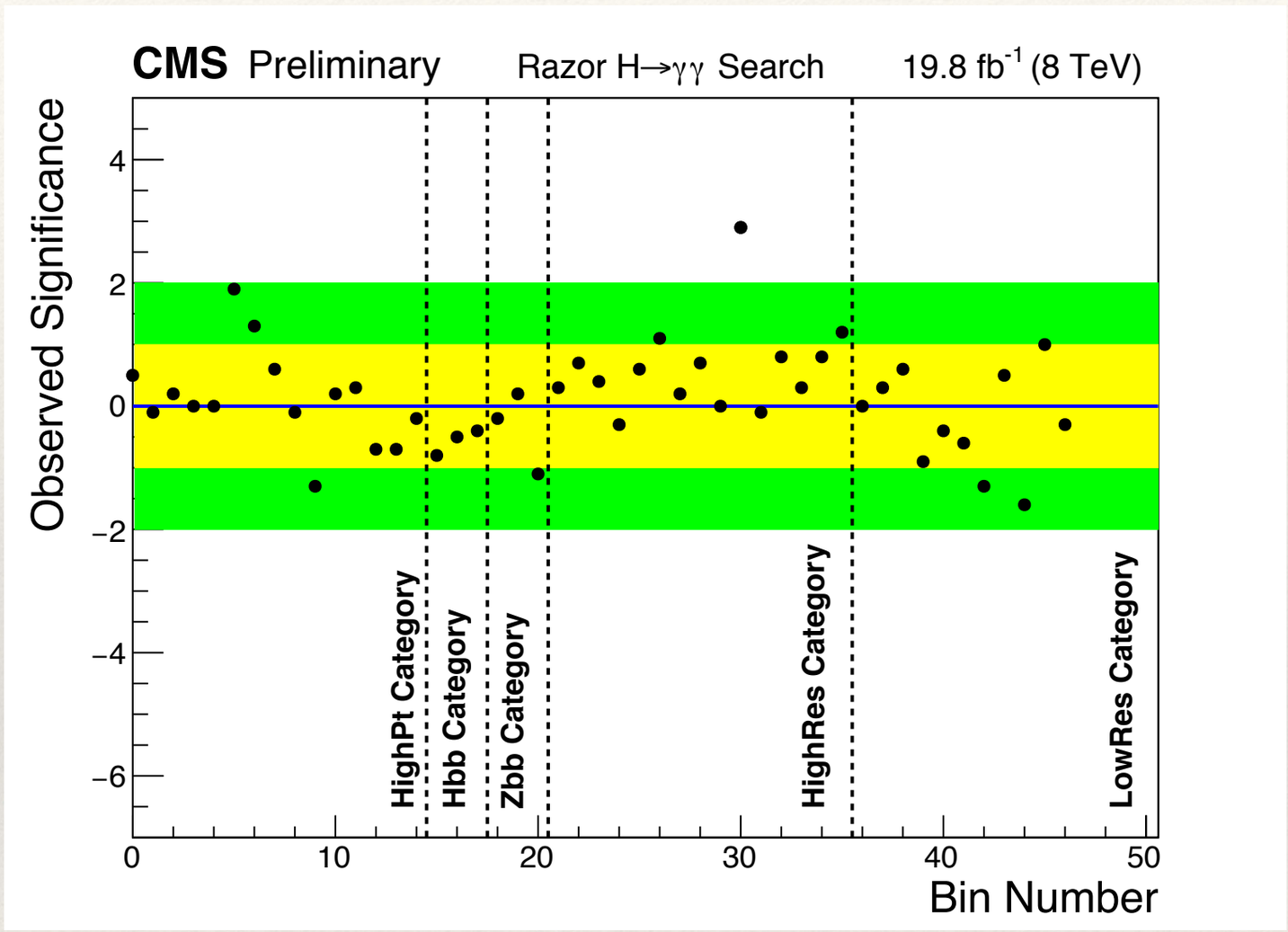
CMS-SUS-14-002, PRD 90, 092007 (2014)

Razor h → γγ

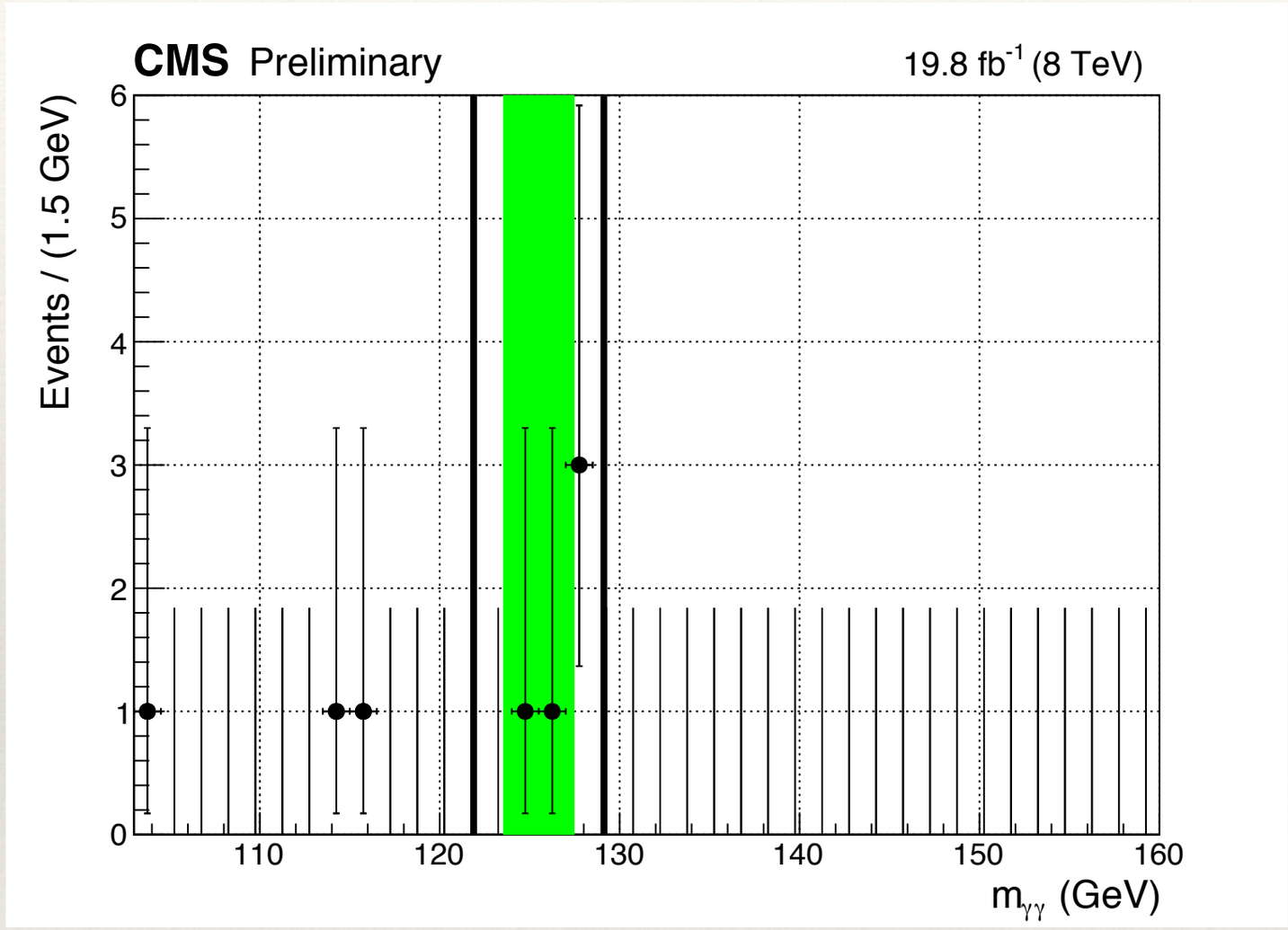
Event Category	Background Prediction Transfer Factor
`HighPt`	0.162 ± 0.004
`Hbb`	0.212 ± 0.049
`Zbb`	0.204 ± 0.032
`HighRes`	0.162 ± 0.002
`LowRes`	0.259 ± 0.002

MC normalization systematic uncertainties		
Source	value	target
luminosity	2.5%	Signal Models, SM Higgs boson MC
trigger efficiency	5%	Signal Models, SM Higgs boson MC
Higgs boson theory	$2\% - 8\%$	SM Higgs boson MC
signal theory x-sec uncertainty	$\approx 13\%$	
Object-level systematic uncertainties		
jet energy scale	shape (3%)	Signal Models, SM Higgs boson MC
photon energy and resolution	shape (1%)	Signal Models, SM Higgs boson MC
b-tagging ID	shape $(0 - 4\%)$	Signal Models, SM Higgs boson MC
σ_E/E uncertainty	shape	Signal Models, SM Higgs boson MC
Normalization & shape systematic uncertainties		
background prediction uncertainty	$1\% - 50\%$	background shape
sideband yields	$1 - 100\%$	low event yields in the data sidebands
fit choice	$\approx 1\%$	background normalization
MC statistics	varies	statistics in SM Higgs boson and SMS MC

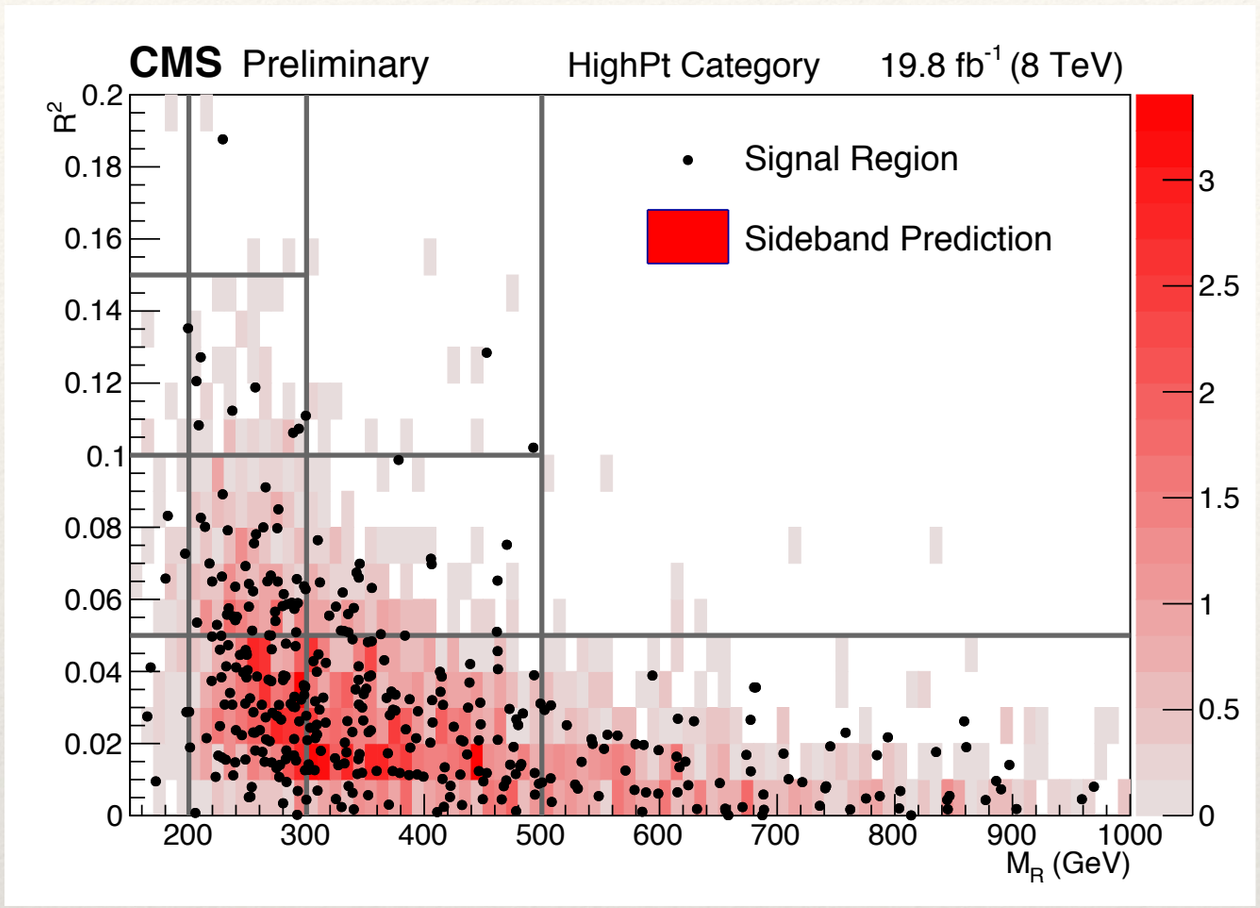
Razor h → γγ

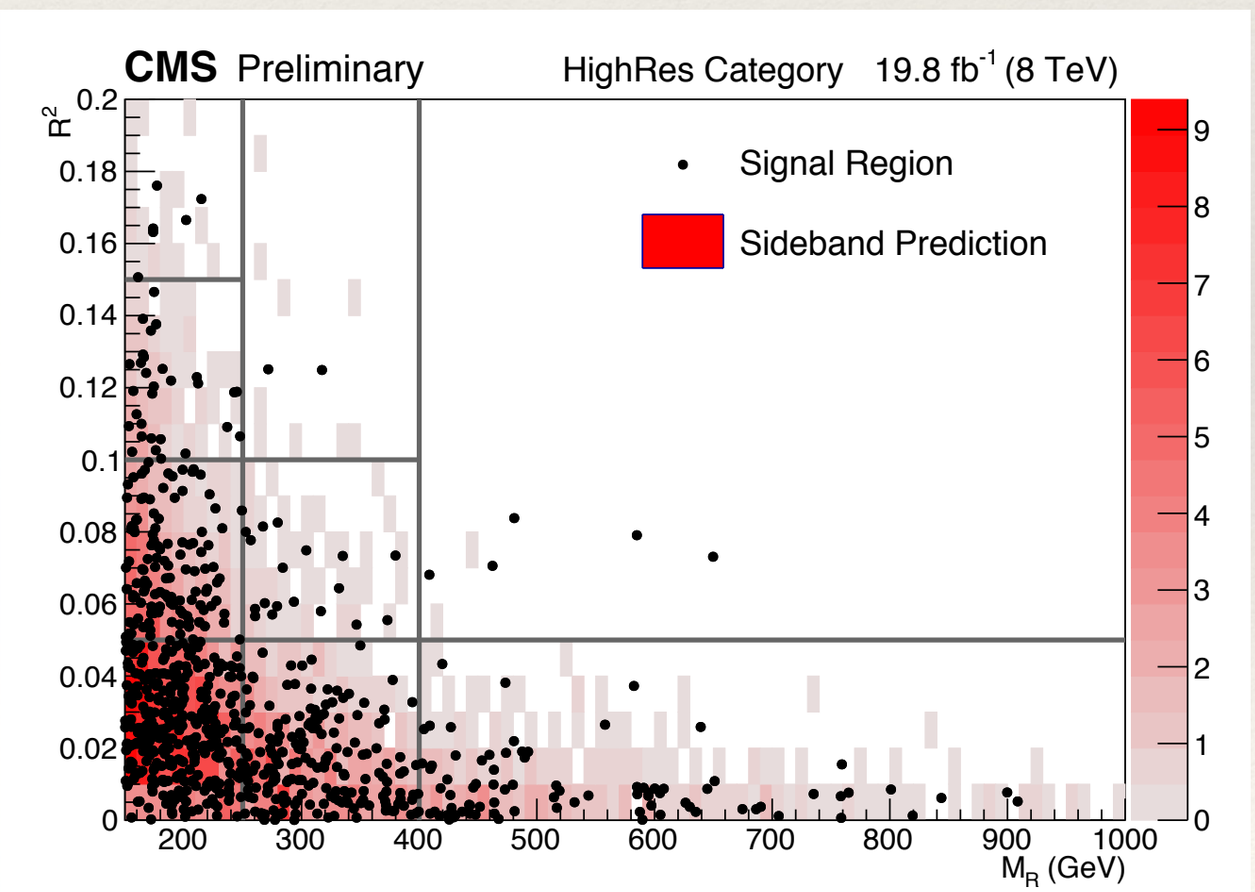

CMS Preliminary
Razor H→γγ Search
19.8 fb-1 (8 TeV)
Observed Significance
4
2
0
−2
−4
−6
HighPt Category
Hbb Category
Zbb Category
HighRes Category
LowRes Category
0
10
20
30
40
50
Bin Number

Razor h → γγ


CMS Preliminary
19.8 fb-1 (8 TeV)
Events / (1.5 GeV)
0
1
2
3
4
5
6
110
120
130
140
150
160
mγγ (GeV)

Razor h → γγ


CMS Preliminary
HighPt Category
19.8 fb-1 (8 TeV)
Signal Region
Sideband Prediction
R2
MR (GeV)


CMS Preliminary
HighRes Category
19.8 fb-1 (8 TeV)
Signal Region
Sideband Prediction
R2
MR (GeV)