



# Search for New Physics in the Low MET Monophoton Channel with the CMS Detector

Toyoko Orimoto, Northeastern University  
APS DPF Conference  
5 August 2015

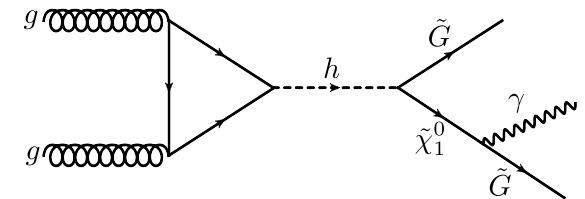
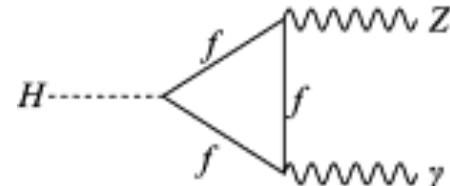
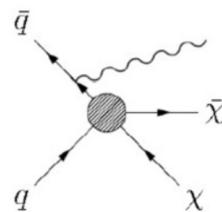




# Monophotons: A Powerful Tool for Constraining BSM



- Low  $E_T$  monophoton ( $\gamma + \text{MET}$ ) search can constrain:
  - **Dark Matter:** At LHC, DM ( $\chi$ ) can be pair produced via  $q\bar{q} \rightarrow \gamma \chi\chi$ ; Traditional search is in high energy regime
  - **SM  $H \rightarrow Z(\rightarrow \nu\nu)\gamma$ :** Both  $H \rightarrow \gamma\gamma$  &  $H \rightarrow Z\gamma$  are only possible through loops, making them sensitive to new physics
    - Low sensitivity with Run I data due to small rate and challenging background
  - **Exotic Higgs Decays:** In framework of supersymmetry





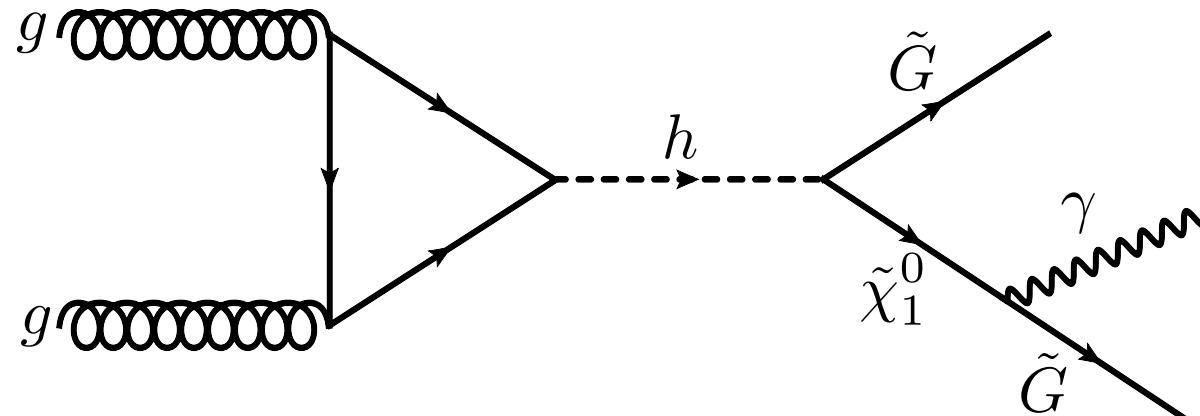
# Exotic Higgs Decays to Low $E_T$ Monophoton



- Low-scale ( $\sim$ TeV) SUSY breaking provides possibility for exotic Higgs decays into monophoton channel

SM Higgs boson (125 GeV)  
produced via gluon fusion

Neutralino NLSP decays promptly  
into photon + gravitino LSP



Higgs decays to neutralino  
NLSP + gravitino LSP

For neutralino mass  $m_\chi < m_h/2$ , Higgs  
favors decay into 2 neutralinos ( $\gamma\gamma$ +MET)



# Backgrounds Estimated with Combo of Data-Driven and MC



## Irreducible

- $Z(\rightarrow\nu\nu)\gamma$

## Partially Reducible

- $W(\rightarrow l\nu)\gamma$

## Mis-identified Photons

- Jets faking photons\*
  - QCD
  - $Z+jets$
  - $W+jets$
- Electrons faking photons\*
  - $W \rightarrow e\nu$

## Fake MET

- $\gamma+jets$

## Non-Collision

- Beam Halo\*
- Anomalous signals\*



# Discriminating Event Selection



## Trigger

- Central photon with  $E_T > 30 \text{ GeV}$  & MET  $> 25 \text{ GeV}$
- Loose calo-based photon ID and shower shape
- $7.3 \text{ fb}^{-1}$  integrated lumi

## Lepton Veto

- Electrons & Muons:
  - Pass Loose ID
  - $p_T > 10 \text{ GeV}$
  - $\Delta R > 0.3$  separated from  $\gamma$

## MET Selection

- PFlow MET  $> 40 \text{ GeV}$

## Photon Selection

- Barrel only,  $E_T > 45 \text{ GeV}$
- Photon ID: 85% eff
- Pixel seed veto
- $R_9 > 0.9$

## Anomalous Signal Rejection

- $R_9 < 1$ ;  $\sigma_{\eta\eta\eta} > 0.001$ ;  $\sigma_{\phi\phi\phi} > 0.001$ ; Swiss cross  $> 0.9$



# Optimized MET Cuts for Model-Specific Selection



## Jet Selection

- PF jets with anti- $k_T$  0.5
- $p_T > 30 \text{ GeV}$  &  $| \eta | < 2.4$
- Separated from  $\gamma$   $\Delta R > 0.5$
- ID based on trajectory of tracks, topology of jet shape, multiplicity of objects used to separate PU jets

## SUSY Analysis

- Min MET  $> 45 \text{ GeV}$ , Prob  $(\chi^2) < 10^{-3}$ , MET Sig  $> 20$
- $M_T > 100 \text{ GeV}$

$$M_T = \sqrt{2 p_T^\gamma E_T (1 - \cos \Delta\phi(\gamma, E_T))}$$

- Scalar sum of  $p_T$  of jets  $H_T < 100 \text{ GeV}$
- Angle between beam direction and major axis of cluster:  $\alpha > 1.2$
- Photon  $E_T < 60 \text{ GeV}$

## Model-Independent Selection

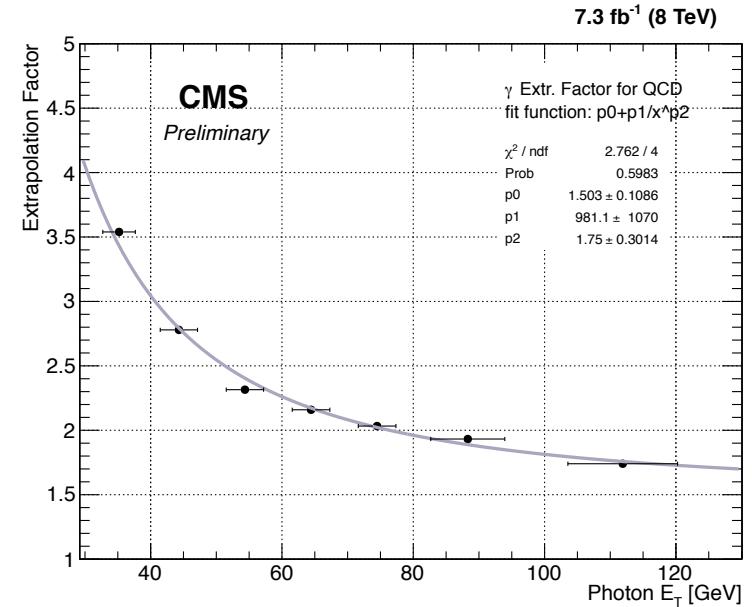
- Reject events with  $\geq 2$  jets
- $\Delta\phi(\gamma, \text{jet}) < 2.5$



# Data-Driven Estimates of Mis-Identified Photons



- Jets fake photons: QCD multijets in which high  $E_T$  jets fragment into isolated  $\pi^0$
- Measure rate in EM-enriched control sample of multijets
- Systematic uncertainty 35%
- Electrons can be misidentified as photons if pixel seed in tracker not reconstructed, mainly from  $W \rightarrow e\nu$
- Electron-faking- $\gamma$  rate of pixel seed veto (PSV) is measured from data using a tag-and-probe method with  $Z \rightarrow ee$  events
- $R = 2.38 \pm 0.03\%$  with systematic uncertainty of 6%

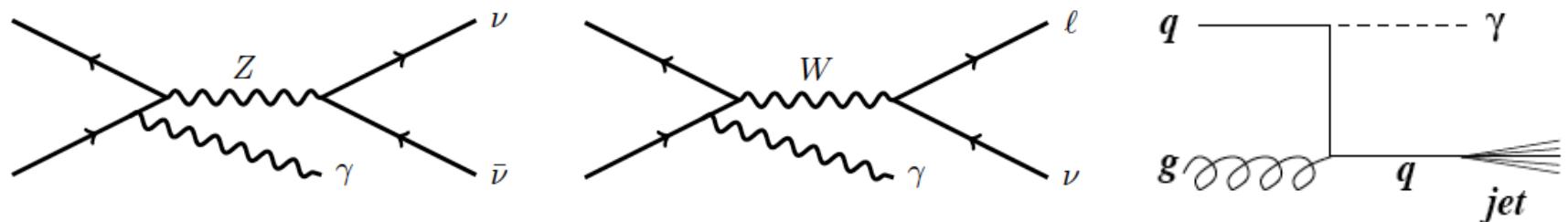




# MC Based Backgrounds



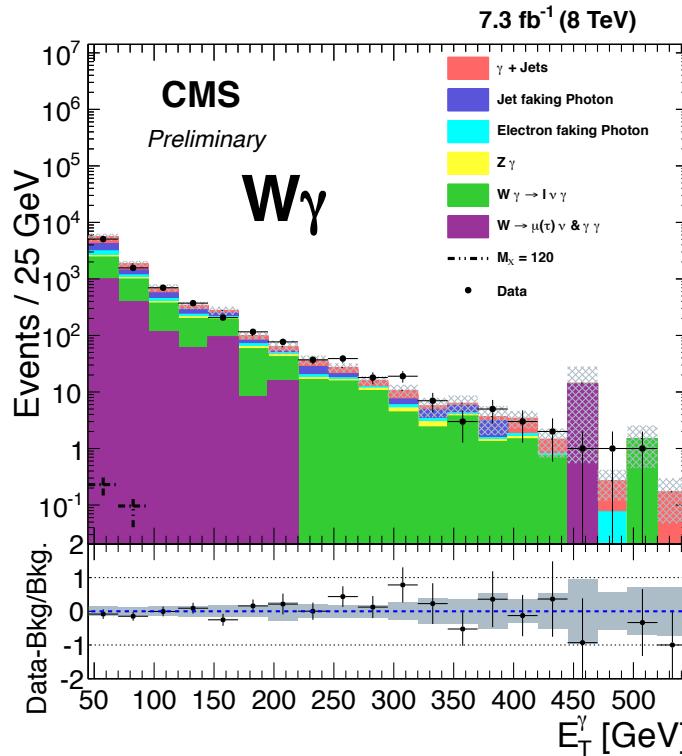
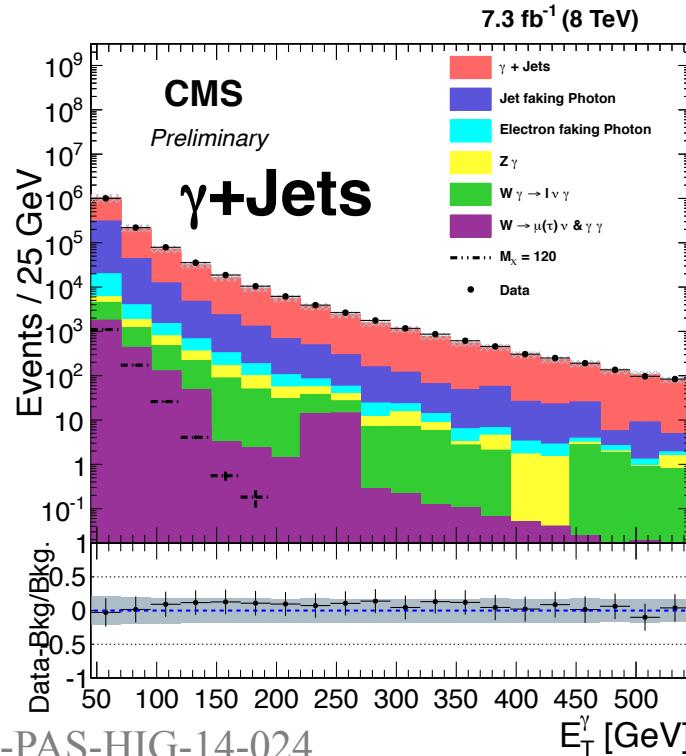
- $Z(\nu\bar{\nu}) + \gamma$  and  $W(l\nu) + \gamma$ : Simulated at LO with MadGraph
  - NLO cross-sections from MCFM
- $\gamma + \text{Jet}$ : generated with MadGraph
  - Data driven technique to adjust the cross section in two event classes: 0-jet and  $\geq 1$  jet
  - Data control sample from pre-scaled single photon trigger events with MET requirement reversed
  - Correction factor is 1.7 for 0-jet, 1.1 for  $\geq 1$  jet
  - 16% systematic uncertainty





# Control Regions to Validate

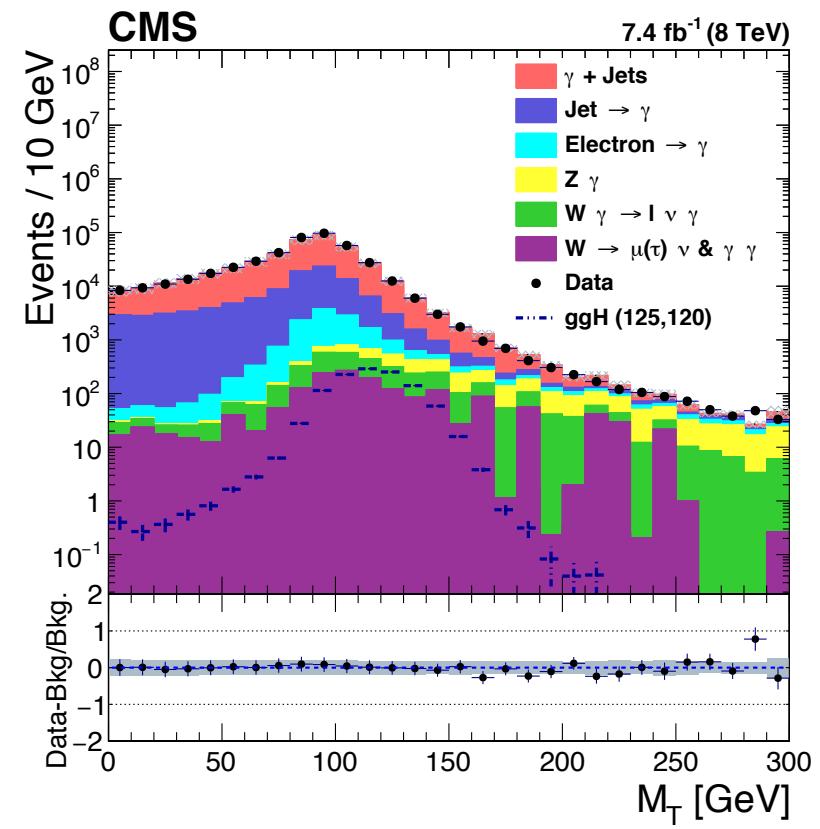
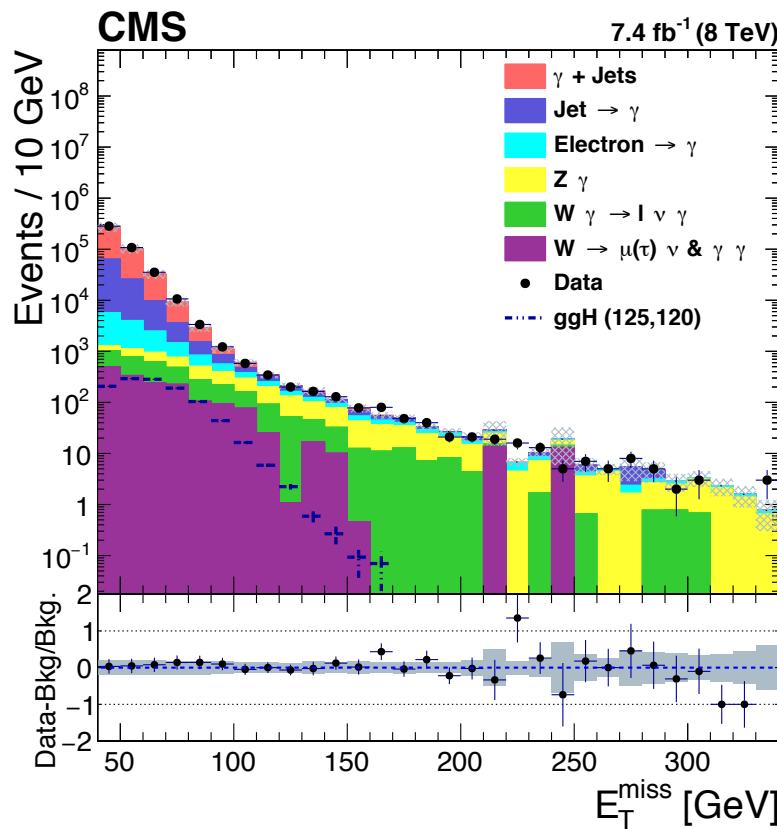
- Two control regions used to check that data are well modeled through MC and data driven methods described
  - $\gamma + \text{Jets}$ : defined by kinematic cuts, anomalous signal rejection and lepton veto
  - $W\gamma$ : defined by inverting lepton veto at preselection level





# Model Independent Results

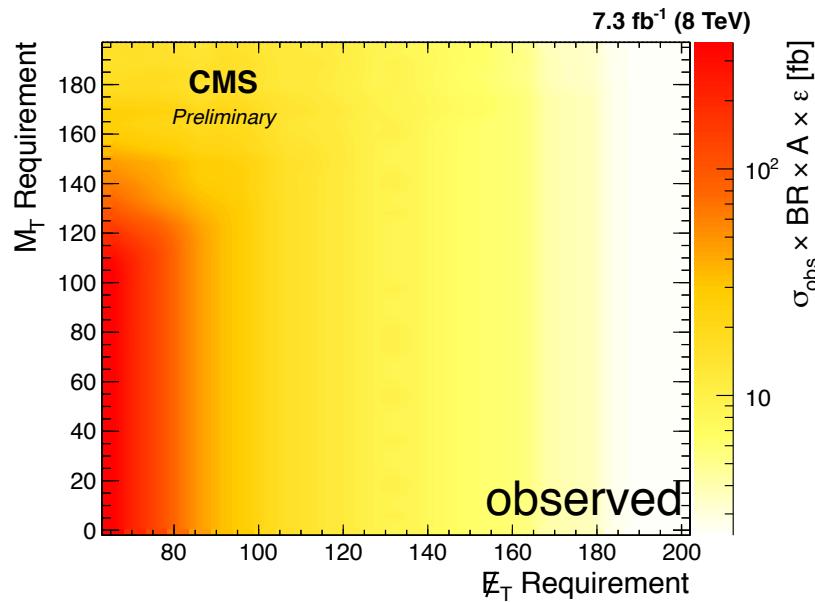
- Results for generic signal with model-independent selection
- Less discriminating power, but less model dependence



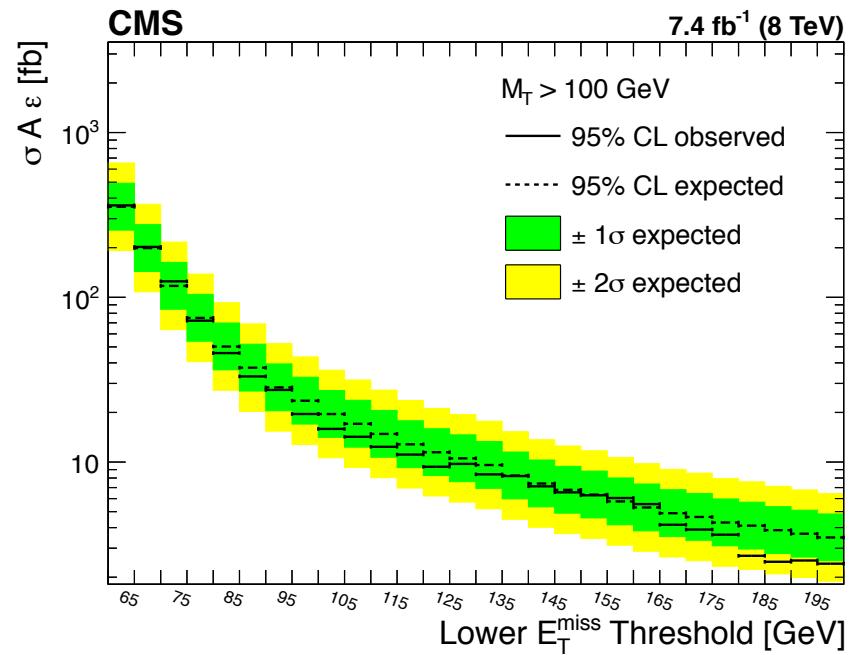


# Model Independent Limits

- Asymptotic  $CL_s$  method with systematic uncertainties in signal and background predictions treated as nuisance parameters with log-normal prior distributions



Process	of Events
$\gamma + \text{jets}$	$(313 \pm 50) \times 10^3$
$\text{jet} \rightarrow \gamma$	$(906 \pm 317) \times 10^2$
$e \rightarrow \gamma$	$(1035 \pm 62) \times 10^1$
$W(\rightarrow \ell\nu) + \gamma$	$2239 \pm 111$
$Z(\rightarrow \nu\bar{\nu}) + \gamma$	$2050 \pm 102$
Other	$1809 \pm 91$
Total background	$(420 \pm 82) \times 10^3$
Data	$442 \times 10^3$



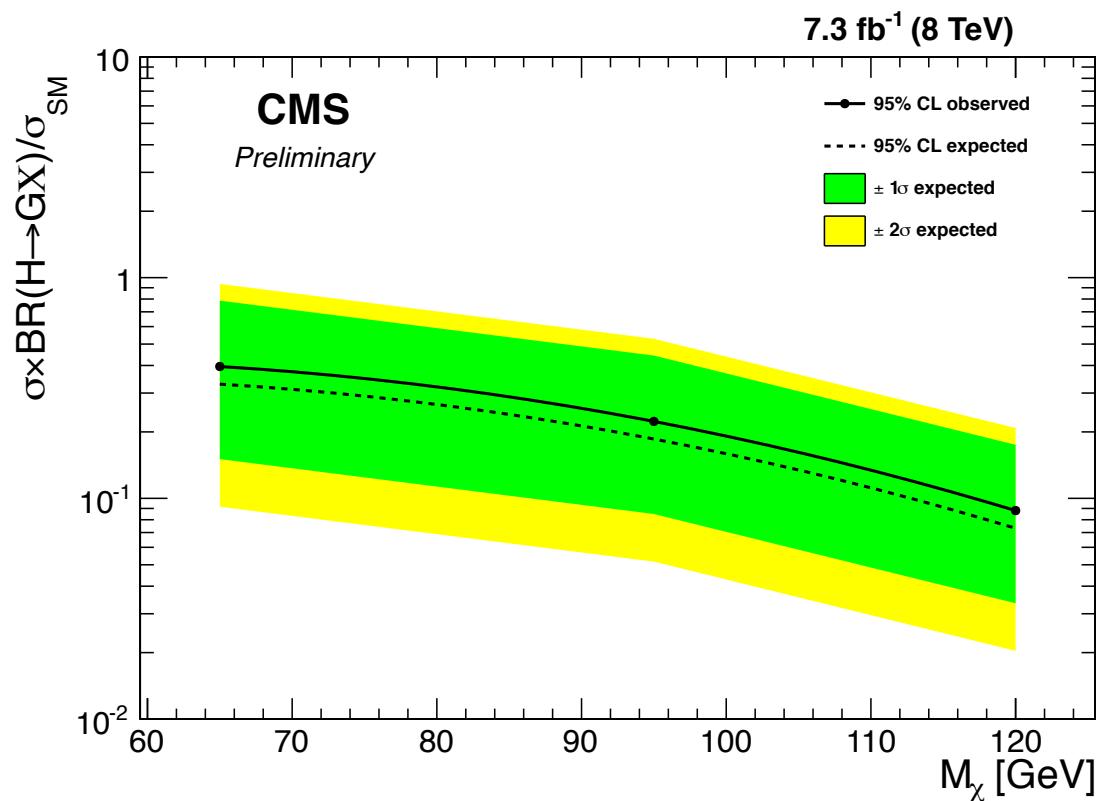


# SUSY Higgs Limits



- Supersymmetric decay of Higgs:  $gg \rightarrow h \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \gamma \tilde{G}\tilde{G}$
- Includes misidentified MET rejection and thus better S/ $\sqrt{B}$

Process	Estimate
$\gamma + \text{jets}$	$179 \pm 28$
$\text{jet} \rightarrow \gamma$	$269 \pm 94$
$e \rightarrow \gamma$	$355 \pm 28$
$W(\rightarrow \ell\nu) + \gamma$	$154 \pm 15$
$Z(\rightarrow \nu\bar{\nu}) + \gamma$	$182 \pm 13$
Other	$91 \pm 10$
Total background	$1232 \pm 188$
Data	1296
$M_{\tilde{\chi}_1^0} = 65 \text{ GeV}$	$653.0 \pm 77$
$M_{\tilde{\chi}_1^0} = 95 \text{ GeV}$	$1158.1 \pm 137$
$M_{\tilde{\chi}_1^0} = 120 \text{ GeV}$	$2935.0 \pm 349$

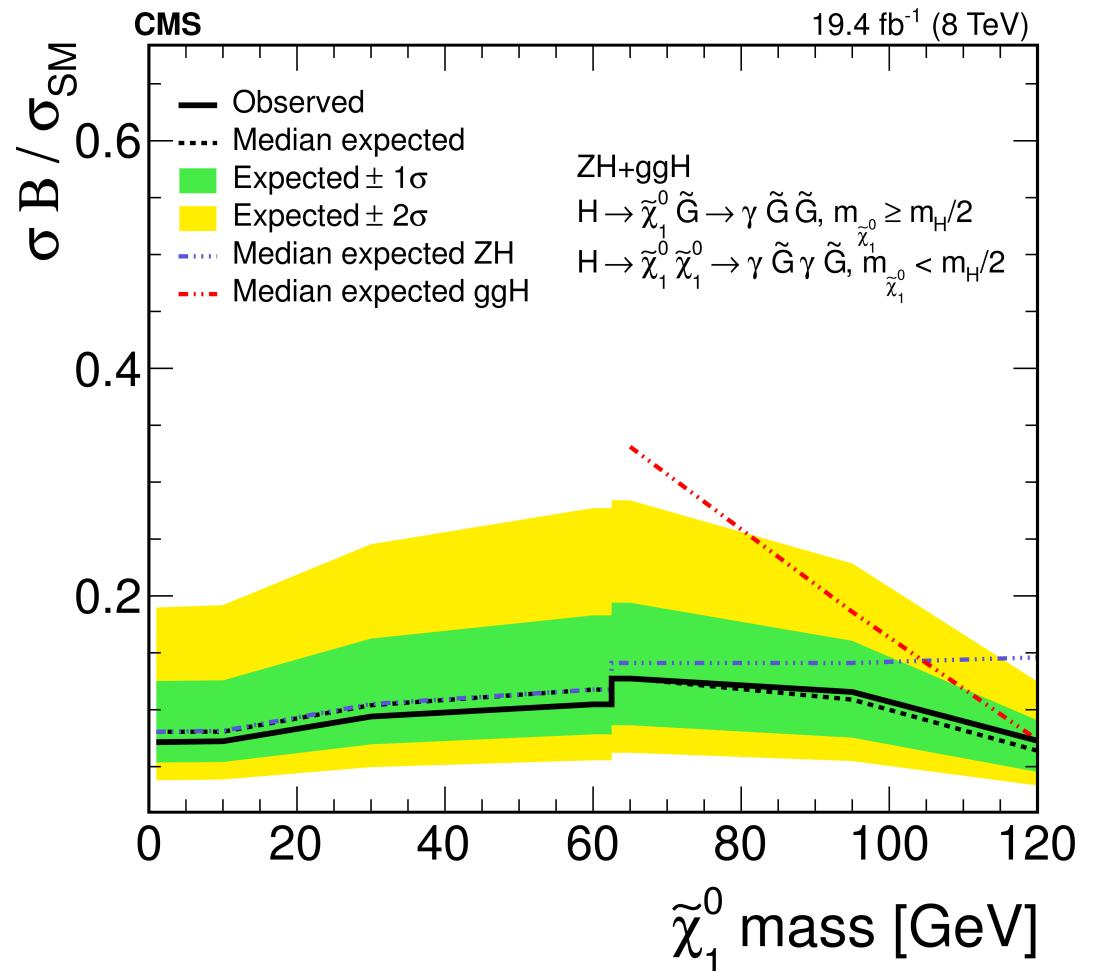
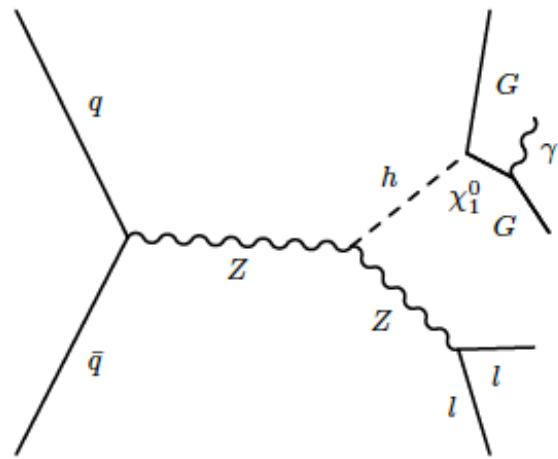




# Improve Sensitivity by Combining with ZH



- CMS also searches for Higgs produced in association with Z
- Less signal, but less background





# Conclusions



- Monophoton signatures at the LHC are phenomenologically rich, potentially providing a path to discover exotic decays of the Higgs, dark matter, or other BSM physics
- Low  $E_T$  monophoton: challenging analysis, yet can probe a complementary phase space to the traditional high energy search and constrain low scale SUSY breaking
- <https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig14024TWiki>
- <http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-14-025/index.html>

