Higgs Hunting 2015

Search for the exotic decay of the Higgs boson in the low E_T Monophoton final state @ CMS

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On behalf of the CMS collaboration

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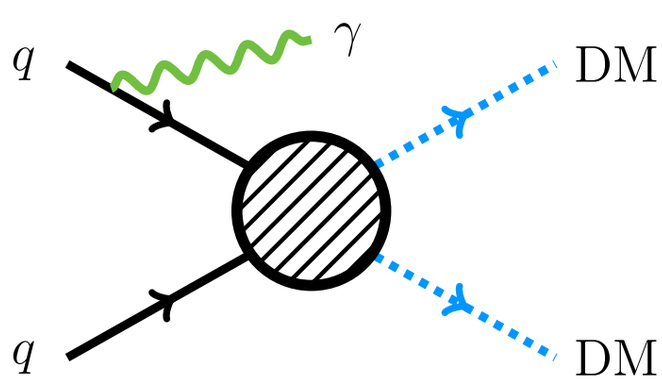
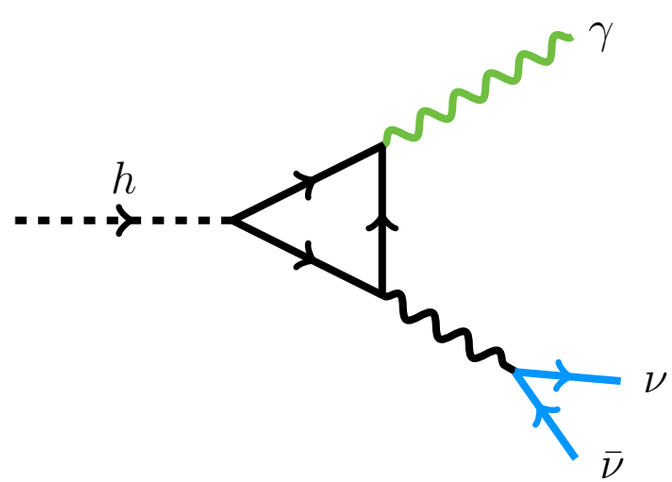
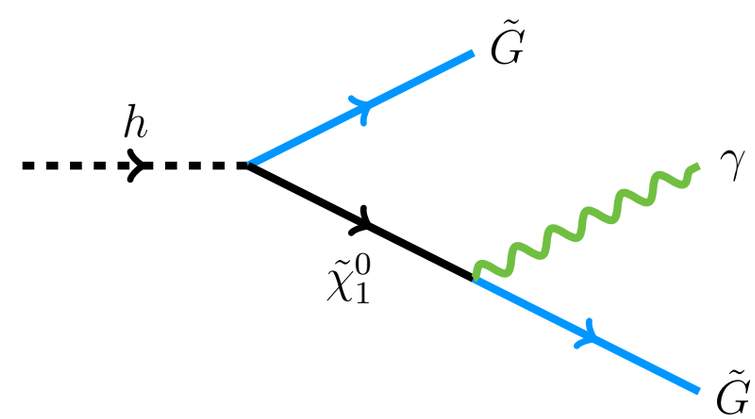
INTRODUCTION

With Low E_T monophoton (γ+MET), we can:

- Extend the reach of the usual monophoton searches for **Dark Matter and other new phenomena** ➤ searches at colliders concentrated at high energy regime
- Look for **SM Higgs decays to Z(νν)γ** ➤ heavy particles in the loop can enhance coupling (not sensitive to SM cross section)
- Look for BSM processes that induce **exotic Higgs decays**







SUSY Higgs Decay to Low E_T Monophoton

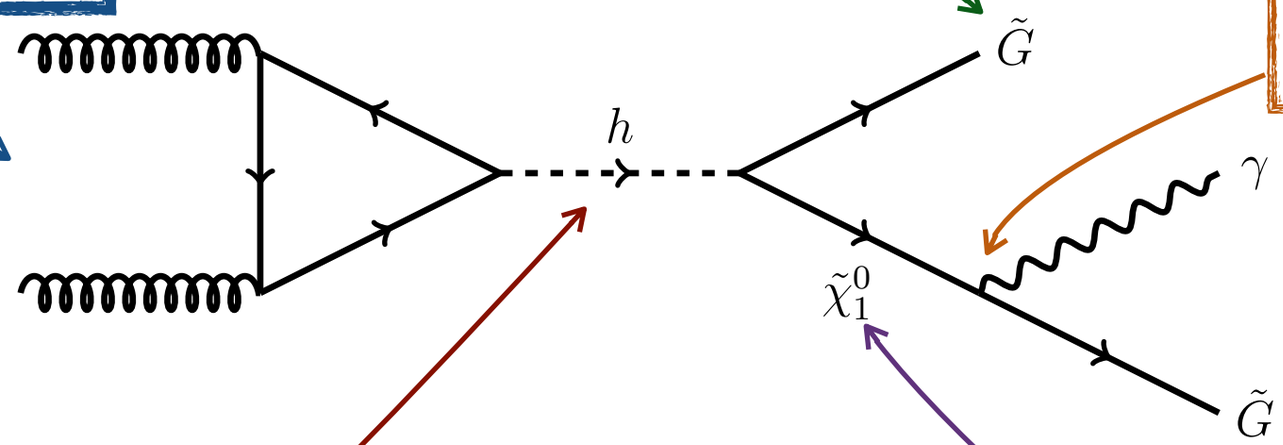
Supersymmetry provides a possible solution for the Electroweak instability and the hierarchy problems

Models with **low scale SUSY breaking (√f ~ TeV)**, in the presence of gravity, provide a gravitino with M ~ 0, and allow the decay $h \to \tilde{\chi}_1^0 \tilde{G}$

Higgs produced via gluon fusion

Gravitino is the model's LSP

Neutralino decays promptly to photon + Gravitino



arXiv:1203.4563v2

Standard Model-like Higgs boson with M_h = 125 GeV decays into a Gravitino and a Neutralino

Neutralino mass $M_{\tilde{\chi}} > M_h/2$
If $M_{\tilde{\chi}} < M_h/2$,
$h \to \tilde{\chi}\tilde{\chi} \to \gamma\gamma$+MET is favored

BACKGROUNDS

Irreducible

- SM Z(→νν)γ (estimated with simulation)

Partially Reducible

- SM W(→νl)γ (estimated with simulation)

Mis-Identified Photons

- Jets faking photons:
  - QCD
  - (W/Z)+Jets
- Electrons faking photons:
  - W→νe
- Data driven estimation

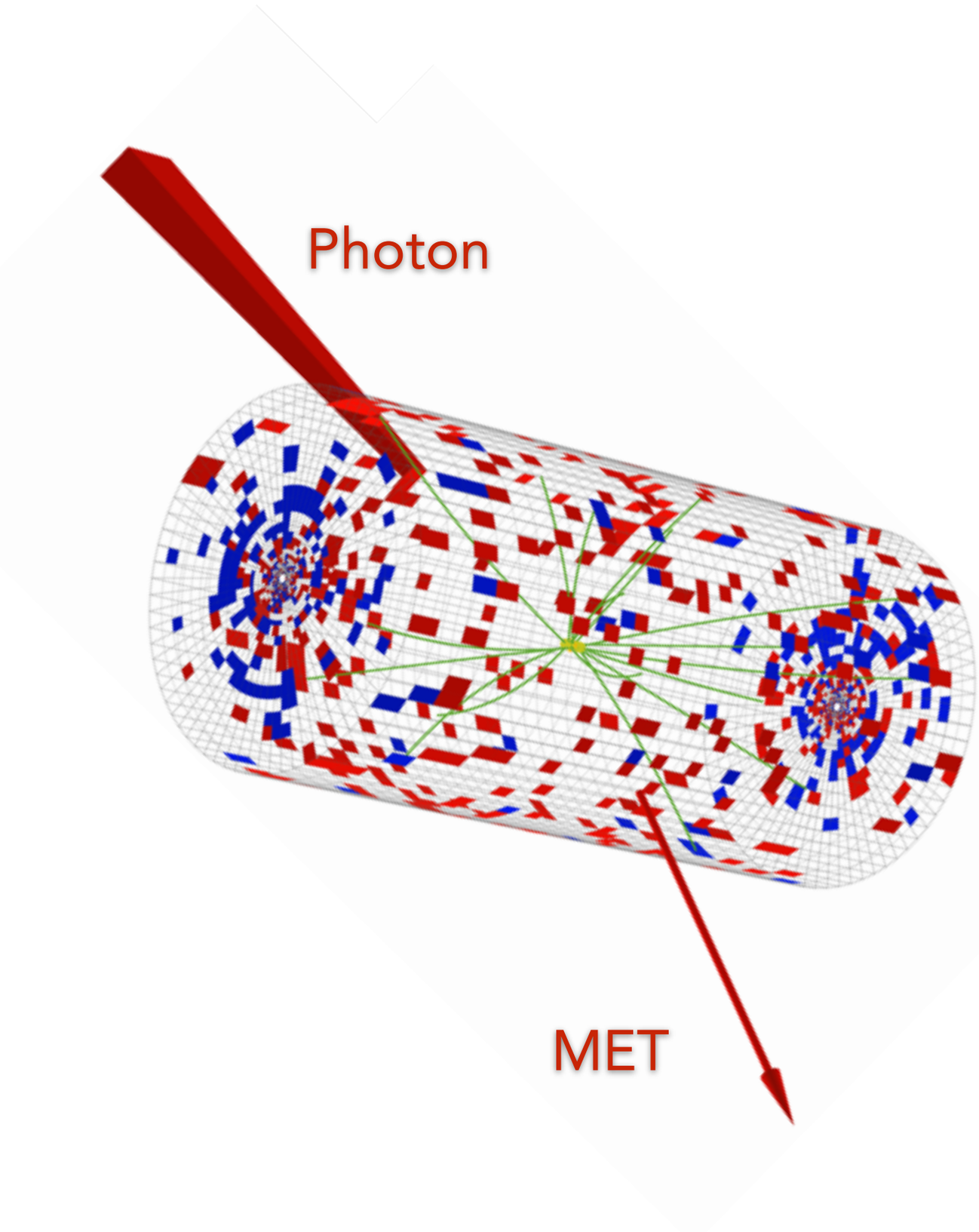
Fake MET

- γ+Jets (simulation + data driven normalization)

Non-Collision

- Beam halo
- Anomalous calorimeter signals
- Data driven estimation

Analysis Strategy



Online selection

- Low E_T isolated photon + MET trigger
  - Possible due to CMS Data Parking program - $\int \mathcal{L} = 7.3\ fb^{-1}$

Offline selection

- Require **one good photon** (ID +Isolation: 85% efficiency) with tight electron veto
  - $E_T > 45$ GeV, $E_T < 60$ GeV and within ECAL barrel
  - Extra shower shape cuts to mitigate anomalous signals
- Require **PF MET** > 40 GeV and $M_T >$ 100 GeV
- **Veto on leptons in the event**
- **Extra cuts to mitigate fake MET**

Fake MET Mitigation

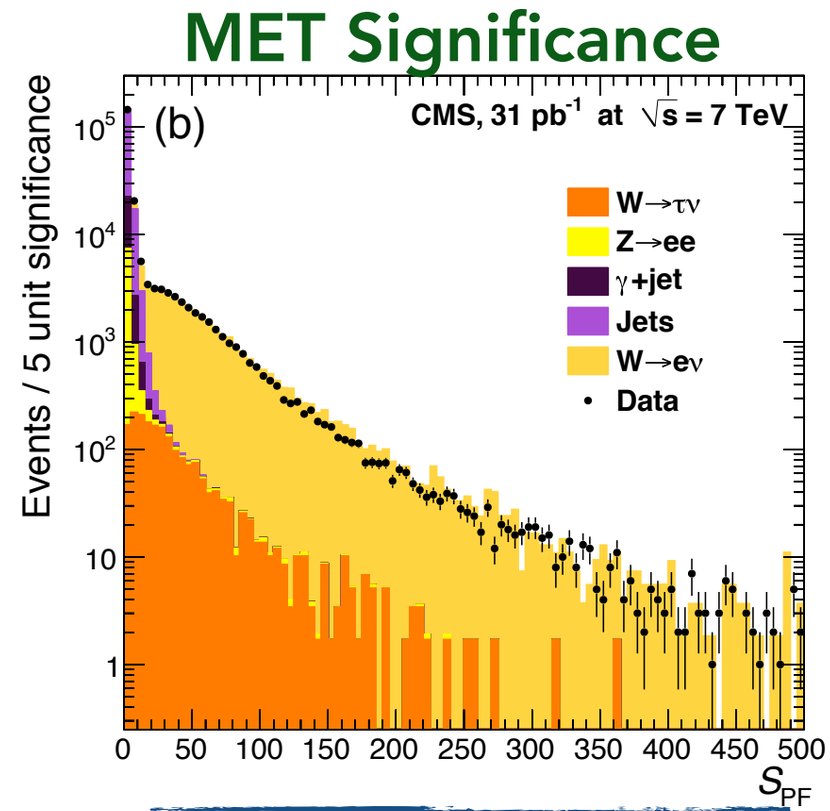
Largest portion of the background is due to MET arising from mismeasured jets ➤ different ways to mitigate this contribution

Hadronic activity requirement in the event

- Cut on the total scalar sum of good jets p_T of the event: **H_T < 100 GeV**
  - *Good jet*: anti-k_T 0.5 particle flow jets with p_T > 30 GeV, outside of the photon cone and identified as a non-pile up jet.

MET Significance

- Cut on the likelihood ratio of MET/no MET hypothesis event by event: **MET Sig > 20**



MET performance of the CMS detector arXiv:1106.5048

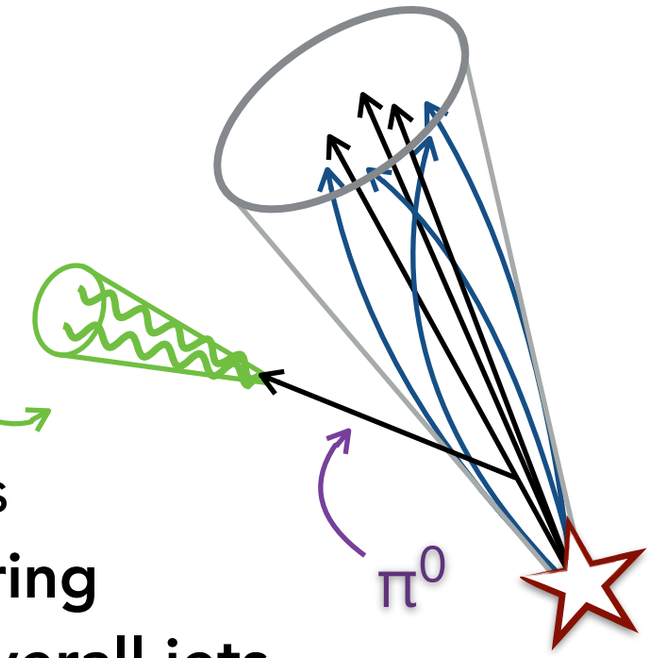
Missing H_T Minimization

- Cut on the probability of missing H_T being created by effects of the energy resolution of jets (based on kinematic fit)

Data Driven Estimations: Fake Photons

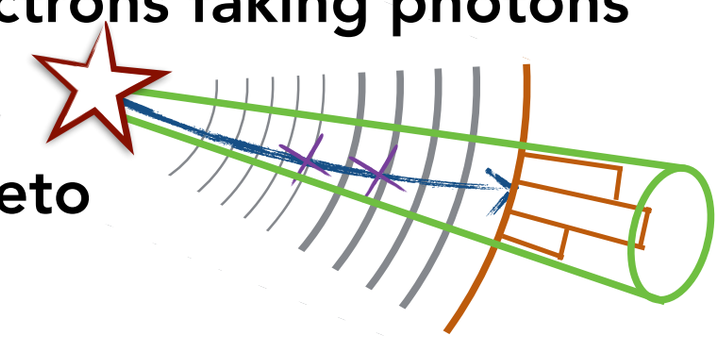
Jets Faking Photons

- High energy π^0 (decaying to $\gamma\gamma$) can fragment from jets and be reconstructed as a single isolated γ on ECAL ➤ **jets faking photons**
- We estimate the contribution of jets faking photons in our signal, as a function of photon E_T, by **comparing templates of jets that pass γ requirements and overall jets**



Electrons Faking Photons

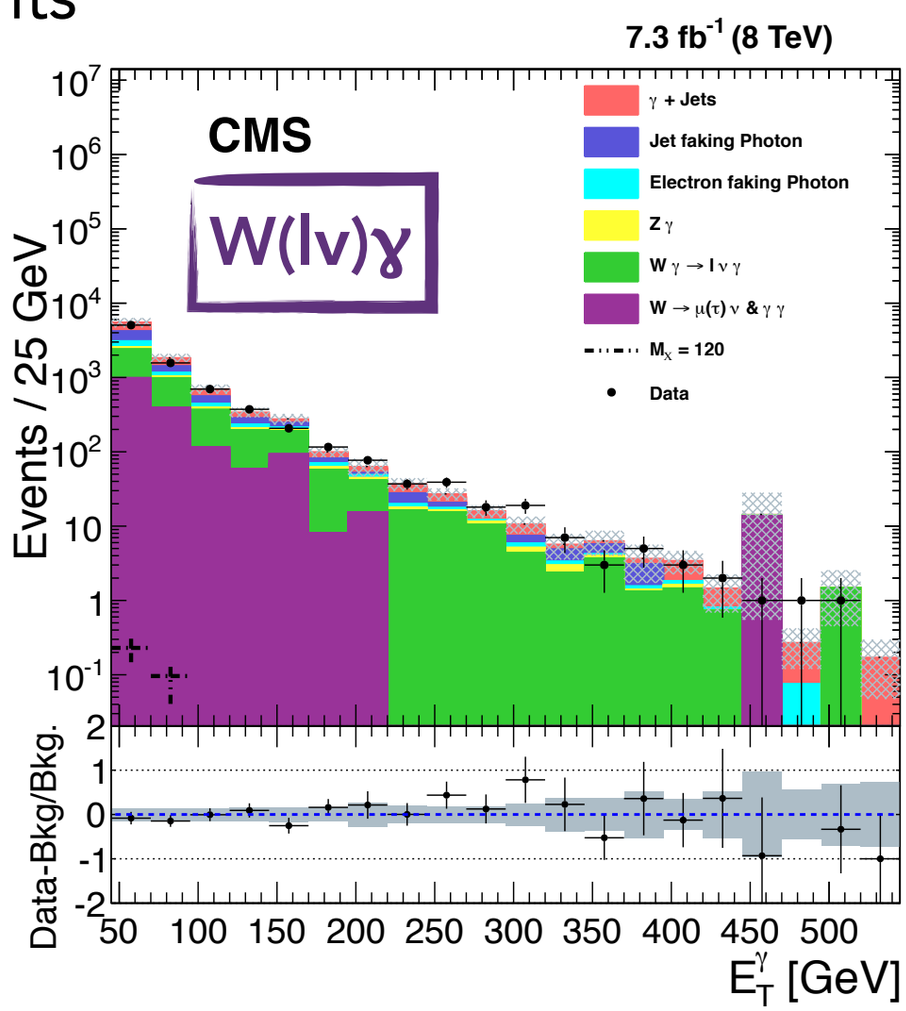
- **Electrons can fail to leave enough hits on the pixel detector** to create a pixel seed, thus failing the pixel seed veto ➤ **electrons faking photons**
- We can estimate that contribution by looking at **how often real electrons (from Z→ee) fail the veto**
- **$(1 - \epsilon_{\text{pixel seed veto}}) = 2.31 \pm 0.03\%$.**

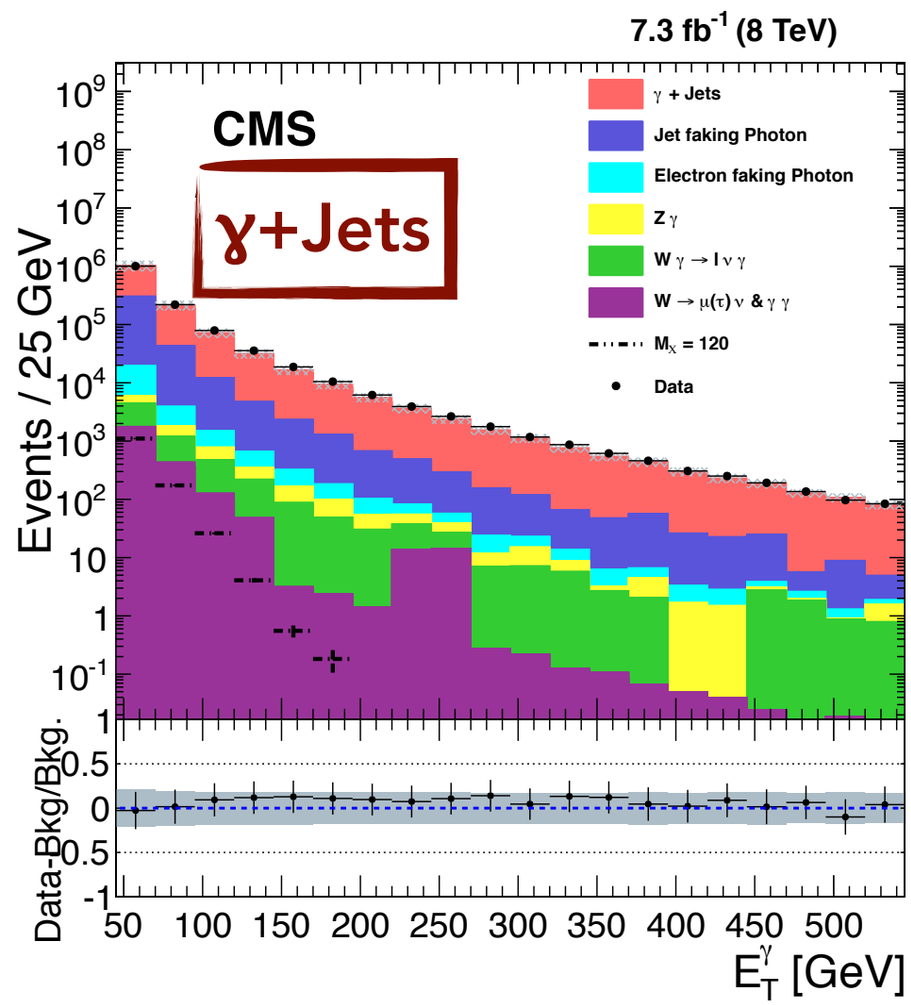


Control Regions

We validate our background modeling with two control regions

- **W(lν)γ**: event selection with reverted lepton veto ➤ enriched with W(lν)γ events, free of signal events
- **γ+Jets**: no fake MET mitigation cuts applied ➤ dominated by γ+Jets events

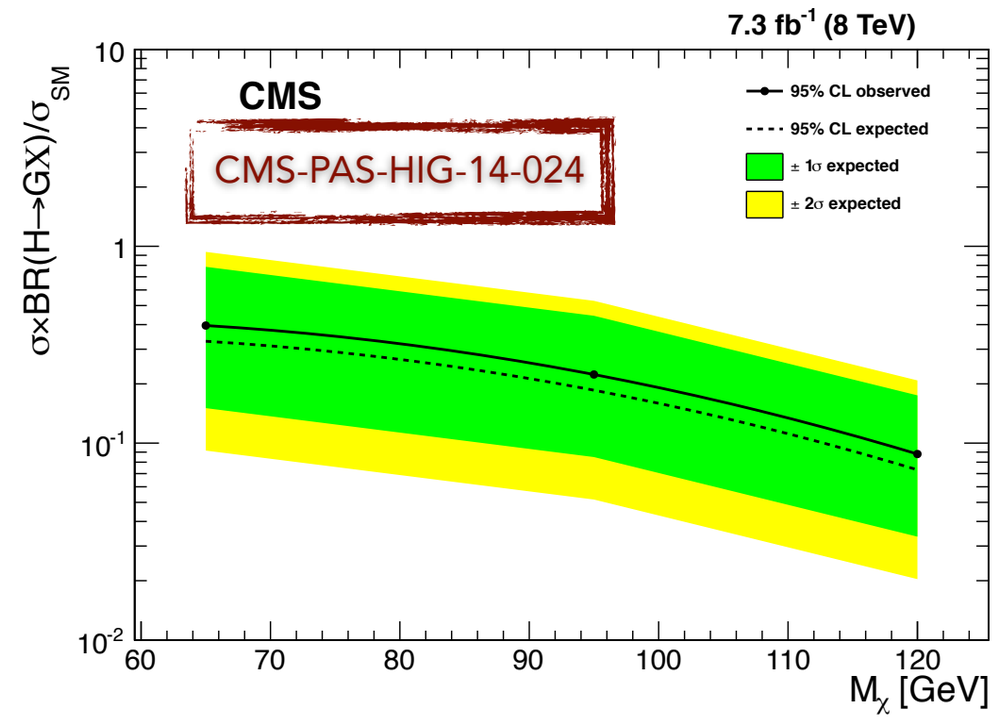




SUSY LIMITS

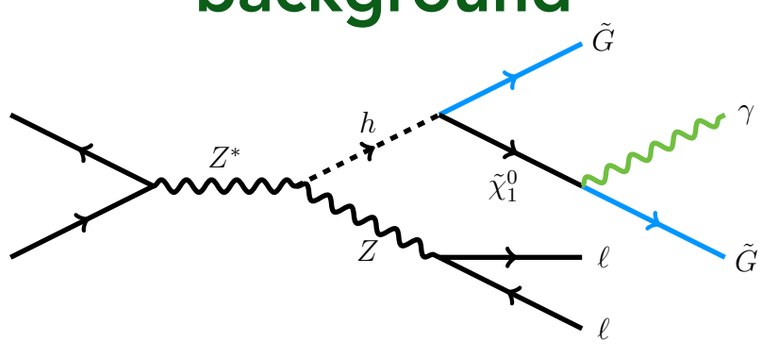
Limits on the exotic process $gg \to h \to \tilde{\chi}_1^0 \tilde{G}$ assuming Standard Model cross section for Higgs production

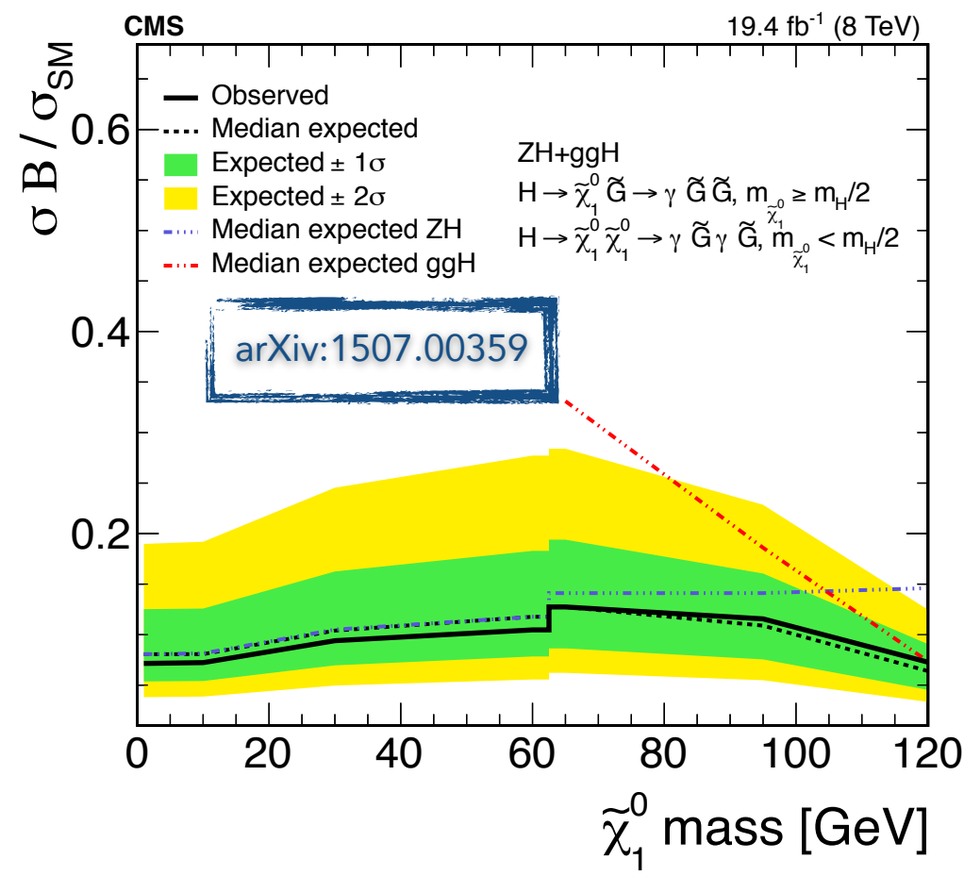
Limits on exotic branching ratio



We can also look at the Higgs being produced in association with a Z boson that decays into two leptons

➤ **Less signal but much less background**





Model Independent Limits

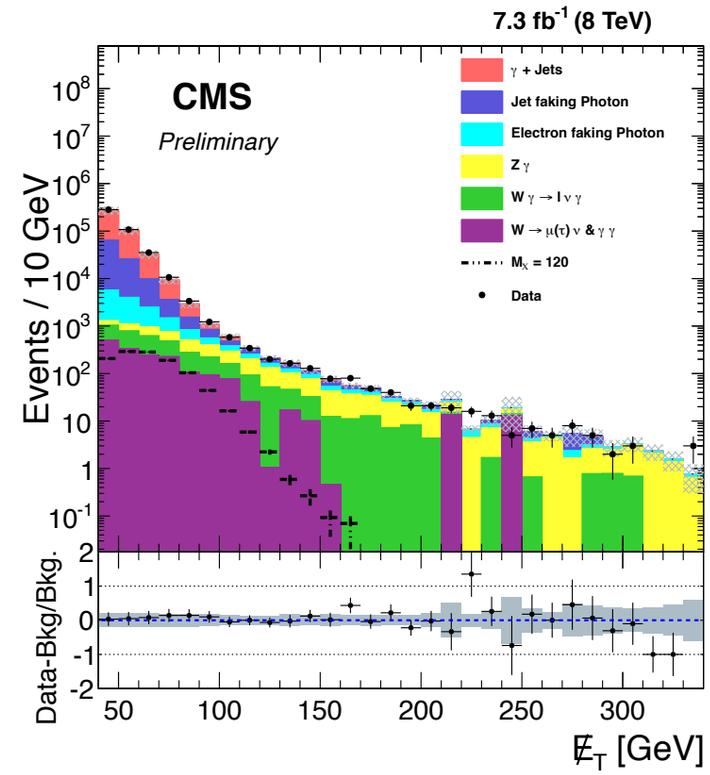
- We can choose to use looser and simpler cuts to provide **model independent results** on studied final state

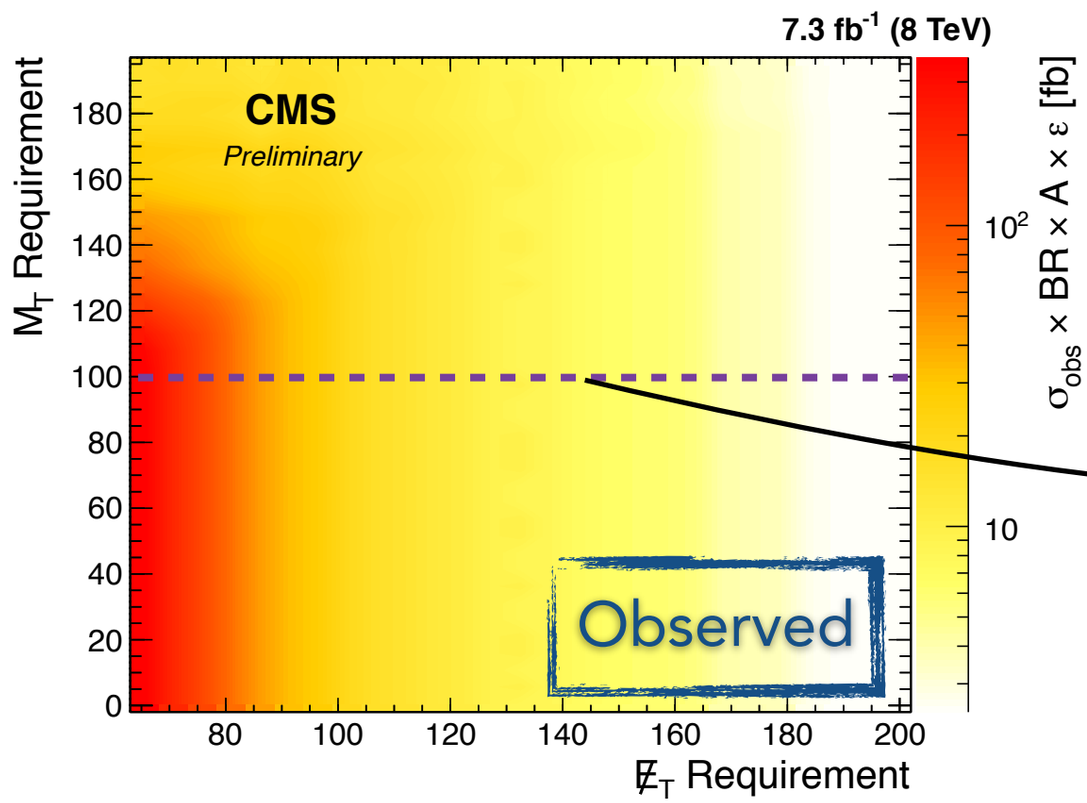
Cuts removed:

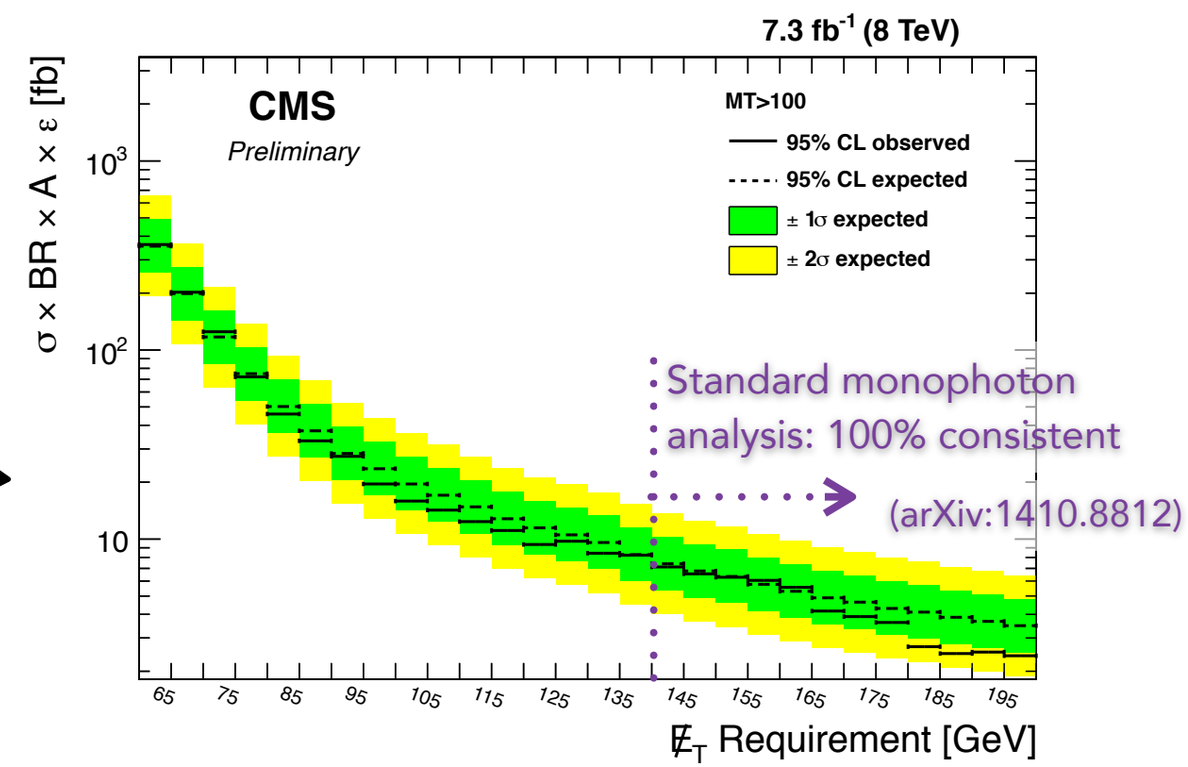
- Fake MET mitigation cuts
- $M_T > 100$ and $E_T < 60$ GeV cuts

Cuts added:

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







SUMMARY

- We have performed a search for an **exotic decay of the Higgs boson on the low E_T monophoton final state**
- As a model independent search, this work **extends the standard search for new physics in the monophoton final state** to a new regime at the LHC
  - Very challenging regime due to triggering and large background
- Within our benchmark model, we have set **limits on a SUSY decay of the Higgs boson into a neutralino and a gravitino** on the gluon fusion and ZH production channels
- **More information:**
  - 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

BACKUP

Full Event Selection

Trigger

- Low E_T Photon+MET trigger on CMS Data Parking program
- Photon on the ECAL barrel ($|\eta| < 1.4$), $E_T >$ 30 GeV, with calo based ID + isolation and MET > 25 GeV
- **7.3fb^{-1} of integrated luminosity**

Lepton Veto

- Veto electrons and muons that pass loose ID, PT > 10 GeV and outside of the photon cone ($\Delta R > 0.3$)

MET Requirement

- Particle flow MET > 40 GeV
- M_T > 100 GeV

Photon Selection

- At least one photon in the ECAL barrel passing:
  - E_T > 45 GeV and E_T < 60 GeV
  - ID+Isolation with 85% efficiency
  - Electron veto (no pixel seed in the photon cone)
  - Shower shape cuts (anomalous signals mitigation)

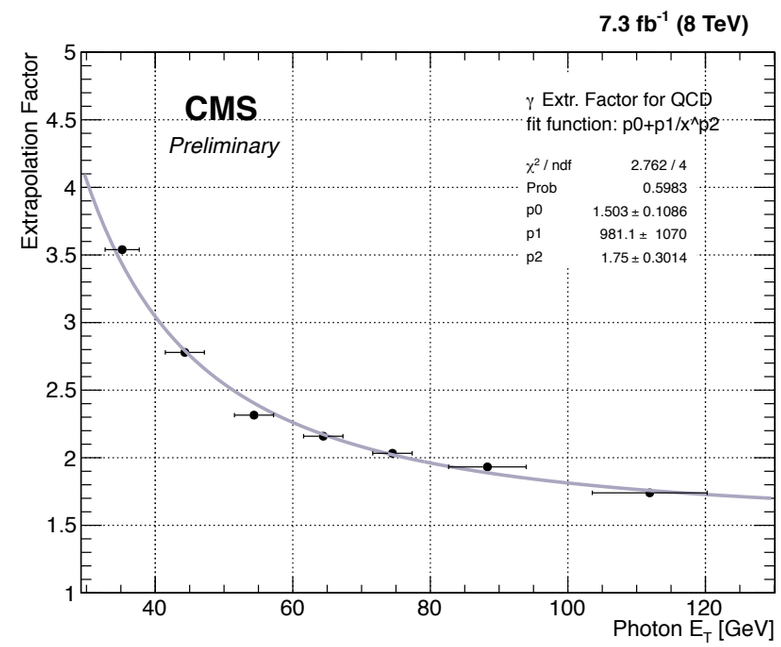
	Model-independent		SUSY benchmark model		
Selection requirements	$Z\gamma \to \nu\bar{\nu}\gamma$	γ+jet	$Z\gamma \to \nu\bar{\nu}\gamma$	γ+jet	$m_{\tilde{\chi}_1^0} = 120$ GeV
Number of jets < 2	0.909	0.769	-	-	-
$\Delta\phi(\gamma,\text{jet}) < 2.5$ radians	0.834	0.262	-	-	-
Transverse mass > 100 GeV	-	-	0.867	0.292	0.829
$H_T < 100$ GeV	-	-	0.785	0.188	0.804
$\tilde{E}_T^{\text{miss}} > 45$ GeV	-	-	0.761	0.071	0.743
$\text{Prob}(\chi^2) < 10^{-3}$	-	-	0.626	0.033	0.467
E_T^{miss} significance > 20	-	-	0.440	0.001	0.195
$\alpha > 1.2$	-	-	0.390	0.001	0.165
$E_T^{\gamma} < 60$ GeV	-	-	0.074	0.0002	0.106

Analysis dependent selection efficiencies after good photon selection ($E_T(\gamma)$ > 45 GeV, $|\eta(\gamma)| < 1.44$, ID+ISO) and MET > 40 GeV

Fake Photons (Data Driven)

Jets Faking Photons

- In a data control sample (MET < 40 GeV), check the ratio between $\sigma_{i\eta i\eta}$ templates of :
  - Objects passing photon ID (contribution of real photons subtracted) ➤ **jets faking photons in our signal**
  - Objects that pass a loose photon ID+Isolation and failing at least one of the isolation requirements ➤ **jets control sample**
- In our signal sample, we weigh the jets control sample by the measured ratio and use it as our jets faking photons estimation.
- Systematic uncertainty: 35%



Electrons Faking Photons

- In a data control sample requiring one electron, we use a **Tag-and-Probe method** to check the rate in which the probe electron is reconstructed as a photon due to the failing of the pixel seed veto on Z→ee events
- After requiring the tag electron, we construct samples with two different probes: (1) a reconstructed photon that passes the electron veto (electron failing to leave a pixel seed); (2) a reconstructed photon that failed the electron veto.
- The ratio between the yields of the invariant mass of tag and probes under the Z peak provides a factor to be used as normalization of a control sample identical to the signal sample, but with the electron veto reversed on the photon requirements. This normalization factor is related to the pixel seed veto fake rate (1 -$\epsilon_{\text{pixel seed veto}}$).
- **(1 -$\epsilon_{\text{pixel seed veto}}$) = 2.31 ± 0.03%**. Systematic uncertainty on electron control sample of 6%.

Background Estimation Simulation Based

γ+Jets

- Generated with MadGraph
- Data driven approach to the cross section scale factor in two event classes: 0-jet and ≥ 1-jet
- Obtained on a control sample with a reversed MET cut (< 40 GeV) and using a pre-scaled single photon trigger identical to the signal trigger but without MET requirement
- Correction factors: 0-jet - 1.7, ≥ 1-jet - 1.1
- Systematic uncertainty: 16% on the number of events

SM W(→νl)γ/Z(→νν)γ

- Simulated at LO with MadGraph ➤ NLO cross-sections from MCFM

SYSTEMATICS

Systematic uncertainties for SUSY benchmark (model independent in parenthesis) in percentage for the ggH analysis

Source	Signal	Jet$\rightarrow\gamma$	Electron$\rightarrow\gamma$	γ + jet	$Z\nu\nu\gamma$	$W\gamma$
PDF	10 (0)	-	-	-	4 (4)	4 (4)
Integrated luminosity	2.6 (2.6)	-	-	2.6 (2.6)	2.6 (2.6)	2.6 (2.6)
Photon efficiency	3 (3)	-	-	3 (3)	3 (3)	3 (3)
Photon energy scale $\pm$ 1 %	4 (0.5)	-	-	4 (0.5)	4 (0.5)	4 (0.5)
$\vec{E}_T^{miss}$ energy scale	4 (2)	-	-	4 (2)	4 (2)	4 (2)
Jet energy scale	3 (2)	-	-	5 (5)	3 (2)	3 (2)
Pileup	1 (1)	-	-	1 (1)	1 (1)	1 (1)
$Z\nu\nu\gamma$ normalization	-	-	-	-	3 (3)	-
γ+ jet normalization	-	-	-	16 (16)	-	-
$W\gamma$ normalization	-	-	-	-	-	3 (3)
Jet$\rightarrow\gamma$	-	35 (35)	-	-	-	-
Electron$\rightarrow\gamma$	-	-	6 (6)	-	-	-

Event Yields

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

Event yields after full model specific selection

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

Event yields after full model independent selection