Search for supersymmetry in events with photons and missing transverse energy

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Outline

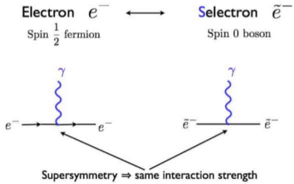
- Introduction-Analysis Overview
- Estimation of Backgrounds
- Systematics
- Results

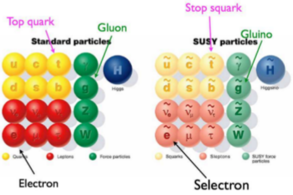
Motivation-Beyond the standard model

Standard Model is a successful theory: measurements are in agreement with prediction.

- the standard model does not include
  - ⋆ Dark matter
    Weakly Interactive Massive Particle (WIMPs)
  - ⋆ Grand Unification
    Color and EWK forces parts of one "Grand Unified" group?
  - ⋆ Gravity
    Not described in SM at all
  - ⋆ Neutrino Mass.
    neutrino oscillation experiments have shown that neutrinos do have mass.
  - ⋆ Hierarchy problem
    why the weak force is 10^{24} times as strong as gravity?

Why Supersymmetry (SUSY)





- predicts the existence of supersymmetric particles (sleptons , squarks, neutralinos and charginos)
- each SM particle would have a superpartner whose spin differs by 1/2
- is not observed yet

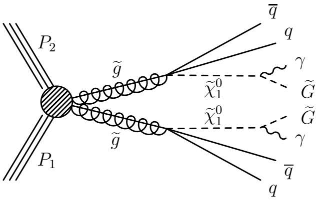
Motivation for SUSY

- provides solution to the hierarchy problem
- provides a dark matter candidate → LSP is stable

Analysis Overview

Search for general gauge mediated (GGM) supersymmetry breaking in final states involving photons.
GGM supersymmetry breaking can produce events with double photons, jets and significant missing energy (E_T^{miss}).

- T5gg model: simplified model of GGM
- R-parity conservation
- SUSY particles are produced in pairs
- Branching ratio: 100%



- Assume gluino pair production where the NLSP neutralino decays to a gravitino and photon ($\tilde{\chi}_1^0 \to \tilde{G}\gamma$), resulting in events with two photons and missing transverse energy.

Backgrounds

Quantum Chromodynamics (QCD) background

- most significant background due to huge QCD cross section
- can have real photons in the final state or we can get electromagnetically-rich jet fragmentation mimicking the response of a photon
- E_T^{miss} comes from mis-measured hadronic activity.

Electroweak (EWK) background

- includes $W\gamma$ and $W + jet$ events
  - $W \rightarrow e\nu$ the electron is misidentified as a photon
  - $W + jet$ events, one of the jets fakes a photon
- genuine E_T^{miss} from the neutrino

Irreducible $Z\gamma\gamma \rightarrow \nu\nu\gamma\gamma$ background

- process with genuine E_T^{miss}
- two real photons in the final state
- modeled via simulation

Dataset Trigger Requirements

We used data from proton-proton collisions collected by the CMS detector in 2016 with center of mass energy $\sqrt{s} = 13\text{TeV}$ and integrated luminosity $35.88 fb^{-1}$.

The data was selected after they satisfied a diphoton trigger.

- Primary photon $E_T > 30$ GeV
- Secondary photon $E_T > 18$ GeV
- Invariant mass of the two photons $M_{\gamma\gamma} > 95$ GeV
- Satisfy Isolation and Shape requirements

Trigger efficiency was measured: 97.2 % efficient.

Object Selection-Photons-Electrons

Photons

- From PF photon Collection
- $P_T > 40 GeV$
- $|\eta| < 1.4442$
- Passes medium photon ID
- Passes Pixel seed veto

Electrons

- From PF photon collection
- $P_T > 40 GeV$
- $|\eta| < 1.4442$
- Passes medium photon ID
- Fails pixel seed veto

Object Selection -Fake Photons- E_T^{miss}

'Fake Photons' are photons that fail isolation or shape requirements.
Primarily composed of electromagnetically-rich jets reconstructed as photons

- Control Sample with fakes are used to model the QCD background
- Make Fakes orthogonal to Photons by inverting charged hadron isolation or shape requirements of the medium photon ID.

Missing Transverse Energy (E_T^{miss})

- results from LSP escaping the detector without interacting
- corrections are applied
- all recommended filters are applied

Lepton Veto is applied:

- Veto on electrons passing medium ID requirements that do not overlap with one of our photon candidates (e,f γ)
- Veto on muons passing loosing ID requirements

Object Cleaning

- $\Delta R(\gamma, e) > 0.3$
- $\Delta R(fake, \gamma) > 0.3$ and $\Delta R(fake, e) > 0.3$

Events are sorted into three categories depending on the selection of their hightest-p_T electromagnetic objects ($\gamma\gamma$, ff, $e\gamma$).

Control and Candidate Sample

Electron-Gamma Sample ($e\gamma$)

- passes primary trigger
- Require $m_{e\gamma} > 105 GeV$
- Require $\Delta R > 0.6$ between electron and photon

Double fake sample (ff)

- Passes the primary trigger
- require $m_{ff} > 105 GeV$
- require $\Delta R > 0.6$ between fakes.

Candidate DiPhoton Sample ($\gamma\gamma$)

- passes primary trigger
- Require $m_{\gamma\gamma} > 105 GeV$
- $\Delta R > 0.6$ between photons

Signal Region consists of all the events with

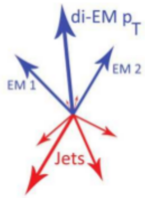
- $E_T^{miss} > 100 GeV$ and two photons.
- 6 signal bins

Control Region events with $E_T^{miss} < 100 GeV$ (signal contamination $< 1\%$)

QCD Background Estimation - Backgrounds without true E_T^{miss}

Strategy

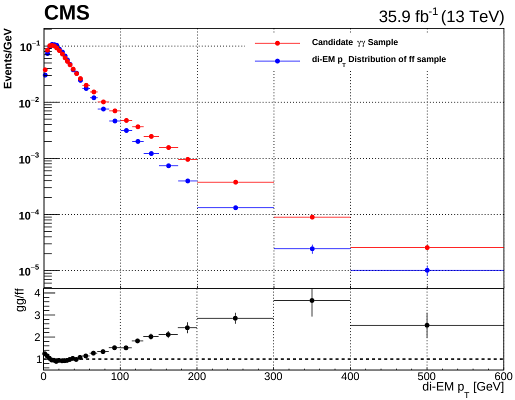
- Processes that lack genuine E_T^{miss}, but can emulate GGM signal topologies if the hadronic activity in the event is poorly measured.
- Used double fakes control sample to estimate the E_T^{miss} distribution of QCD backgrounds.
- But this sample has different amounts of hadronic activity than the candidate $\gamma\gamma$ sample.



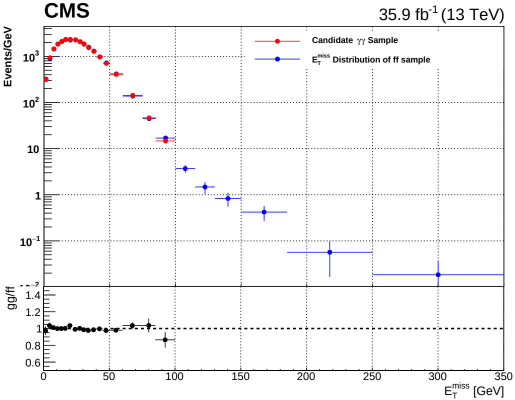
- Model the hadronic recoil of the event with the di-EM p_T of the event, where di-EM p_T is the vector sum of the P_T of the two electromagnetic objects
- Reweight the control samples by (di-EM p_T)$_{\gamma\gamma}$ /(di-EM p_T)$_{ff}$ to correct for the differences in hadronic activity.

- Normalize the ff distribution to $MET < 50 GeV$ region of $\gamma\gamma$

di-EM p_T Distribution of the candidate $\gamma - \gamma$ sample and the control fake-fake sample



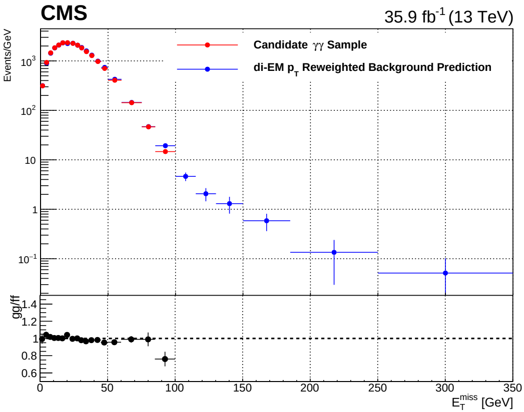
Unweighted E_T^{miss} Distribution



ff distribution is normalized to the $E_T^{miss} < 50 GeV$ region of $\gamma\gamma$

di-EM p_T reweighted E_T^{miss} Distribution

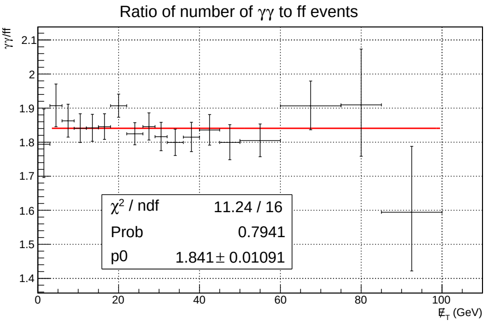
The reweighted ff E_T^{miss} is used as a central value for the QCD background estimate



ff distribution is normalized to the $E_T^{miss} < 50 GeV$ region of $\gamma\gamma$

Cross Check on di-EM p_T- $\gamma\gamma$ ff ratio method

- assume that the relative fraction of $\gamma\gamma$ and ff events does not depend sensitively on the E_T^{miss}
- if so the ratio can be modeled as a simple function.
- multiply the function by the observed number of ff events in our signal region to get an alternate QCD estimate



- di-EM p_T reweighting and gg/ff ratio method give overlapping predictions within the uncertainties
- the difference between two methods is taken as a systematic uncertainty on the overall E_T^{miss} shape.

E_T^{miss} bin (Gev)	Reweighted ff estimate	Ratio method estimate
$100-115$	$69.23^{+15.18}_{-12.68}$	$55.19^{+12.03}_{-10.33}$
$115-130$	$30.89^{+11.76}_{-8.82}$	$22.08^{+8.39}_{-6.59}$
$130-150$	$25.98^{+11.95}_{-8.61}$	$16.55^{+7.56}_{-3.43}$
$150-185$	$20.49^{+10.12}_{-7.11}$	$14.72^{+3.95}_{-5.69}$
$185-250$	$8.74^{+11.65}_{-5.89}$	$3.68^{+4.85}_{-2.47}$
$250-350$	$5.13^{+11.86}_{-4.43}$	$1.84^{+4.23}_{-1.60}$

Systematic Uncertainty of QCD background estimation

Sytematic uncertainty from reweighting procedure

- measured using toy distributions
- each di-EM p_T bin is varied with a Gaussian distribution whose sigma is equal to the statistical uncertainty in each bin

E_T^{miss} Shape uncertainty - uncertainties from the ratio method

- two estimates for the QCD background for each E_T^{miss} bin
- the difference between the two estimates is taken as a symmetric systematic uncertainty

E_T^{miss} (GeV)	QCD Estimate (Events)	Stat. Un.	Shape Un.	Reweighting Un.
$100-115$	69.23	$+15.09, -12.57$	±14.03	±1.66
$115-130$	30.89	$+11.74, -8.79$	±8.81	±1.67
$130-150$	25.98	$+11.86, -8.50$	±9.42	±1.40
$150-185$	20.49	$+10.10, -7.09$	±5.77	±0.55
$185-250$	8.74	$+11.53, -5.65$	±5.06	±1.66
>250	5.13	$+11.79, -4.24$	±3.29	±1.26

EWK background Estimate

EWK background in the signal region ($E_T^{miss} > 100 GeV$) comes mainly from $W\gamma \rightarrow e\nu\gamma$ where the electron is misidentified as a photon.

- Fake rate $f_{e\rightarrow\gamma}$ (AN-2016-470)
- Tag and Probe method with $Z \rightarrow ee$ events
- Assigned 30% systematic

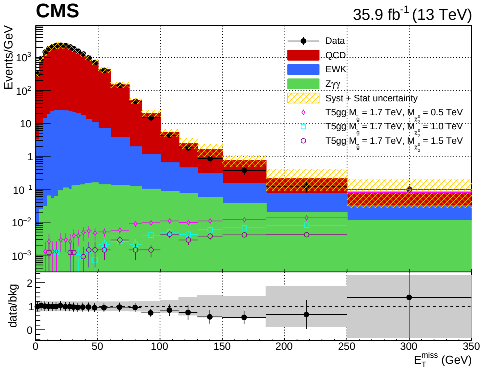
Fake rate is used to calculate a transfer factor which is applied to an $e\gamma$ control sample.
Transfer factor $= f_{e\rightarrow\gamma}/(1 - f_{e\rightarrow\gamma}) = 0.0267 \pm 30\%$.

E_T^{miss} (GeV)	EWK Background Estimate
100-115	8.17 $\pm$2.50
115-130	5.50 $\pm$1.70
130-150	4.78 $\pm$1.48
150-185	3.95 $\pm$1.24
185-250	3.55 $\pm$1.11
> 250	2.11 $\pm$0.69

Irreducible $Z\gamma\gamma \rightarrow \nu\nu\gamma\gamma$ Background

- small contribution from $Z\gamma\gamma$ where Z decays to neutrinos
- two photons and true E_T^{miss}
- modeled via simulation
- assigned a flat uncertainty of 50%

E_T^{miss} bin (GeV)	Expected number of $Z\gamma\gamma$ events
$100 - 115$	1.30 ± 0.65
$115 - 130$	1.14 ± 0.57
$130 - 150$	1.12 ± 0.56
$150 - 185$	1.32 ± 0.66
$185 - 250$	1.28 ± 0.64
> 250	1.14 ± 0.57



$E_T miss$ bin (GeV)	Total expected	Observed
100 − 115	$78.69^{+22.58}_{-20.98}$	65
115 − 130	$37.53^{+16.05}_{-14.04}$	27
130 − 150	$31.88^{+16.44}_{-14.20}$	17
150 − 185	$25.76^{+12.80}_{-10.59}$	13
185 − 250	$13.55^{+13.05}_{-8.31}$	8
> 250	$8.38^{+12.48}_{-5.88}$	10

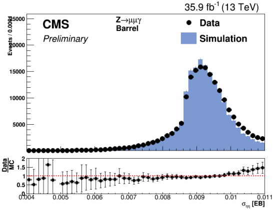
Conclusions

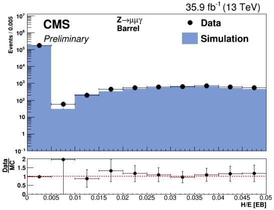
- an analysis of SUSY search is presented on 13TeV using 2016 data
- with 35.9 fb^{-1} we improved our sensitivity compared to a similar analysis with 2015 data.
- no excess is observed with respect to the standard model expectation
- next step $\rightarrow$ to produce exclusion limit plots to exclude gluino masses

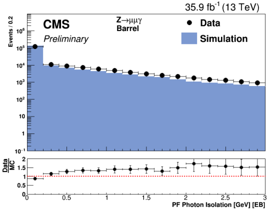
Back Up

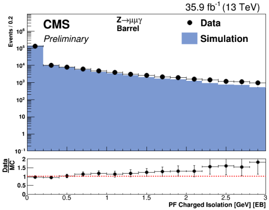
Photon Performance

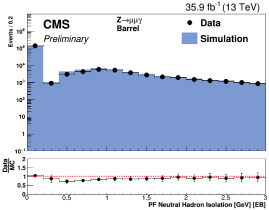
Spring 16 Medium Cut-based Photon ID	
H/E	0.0396
$\sigma_{i\eta i\eta}$	0.01022
ISO_{CH}	0.441
ISO_{NH}	$2.725 + 0.0148 p_T + 0.000017 p_T^2$
ISO_{PH}	$2.571 + 0.0047 p_T$





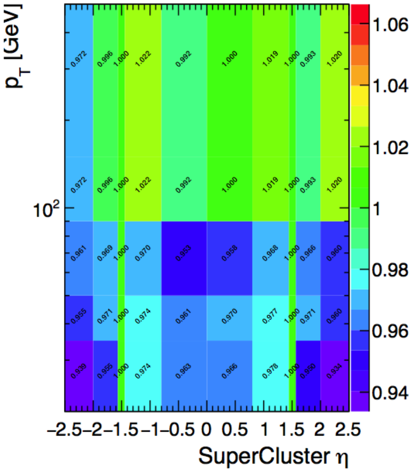


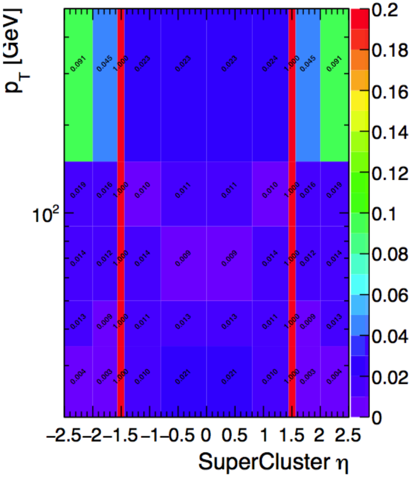




Photon Selection Efficiency

Scale Factors from EGM POG are calulated in bins of photons p_T and η





$H \to \gamma\gamma$ SF Measurements

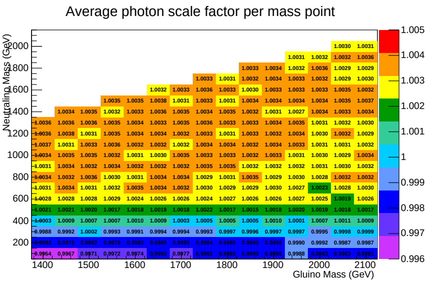
Efficiencies using a tag and probe method with $Z \to ee$

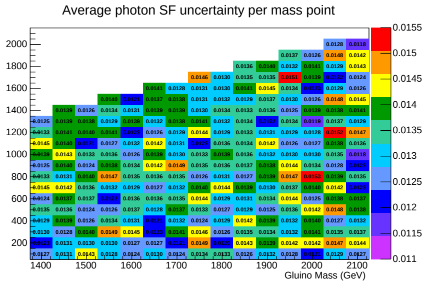
	Data			Simulation		Ratio	
	Eff.	Stat	Syst.	Eff.	Stat.	Eff.	Unc.
Barrel; R_9 >0.85	0.9423	0.0004	0.0018	0.9374	0.0007	1.0052	0.0009
Barrel; R_9 <0.85	0.8225	0.0012	0.0008	0.8258	0.0007	0.9960	0.0017
Endcap; R_9 >0.90	0.9153	0.0007	0.0005	0.9127	0.0009	1.0028	0.0013
Endcap; R_9 <0.90	0.5011	0.0005	0.0139	0.5024	0.0008	0.9974	0.0019

Efficiencies using a tag and probe method with $Z \to \mu^+\mu^-\gamma$

	Data		Simulation		Ratio	
	Eff.	Stat.	Eff.	Stat.	Eff.	Unc.
Barrel; R_9 >0.85	0.9934	0.0008	0.9973	0.0008	0.9961	0.0012
Barrel; R_9 <0.85	0.9737	0.0026	0.9826	0.0041	0.9910	0.0049
Endcap; R_9 >0.90	0.9846	0.0019	0.9853	0.0026	0.9994	0.0033
Endcap; R_9 <0.90	0.9558	0.0107	0.9617	0.0126	0.9939	0.0171

Weighted Average over the mass points





Photon Selection Efficiency

Use official scale factors by the EGM POG for Moriond 2017

- tag and probe method using $Z \rightarrow ee$ events
- weighted average over all photons passing our selection criteria in each SUSY signal mass point.
- Photon Scale Factor $= 1.002 \pm 0.013$
- this value is consistent with $H \rightarrow \gamma\gamma$ measurement using the same trigger and $R9 < 0.5$ cut (HIG-16-020)
- tag and probe method on $Z \rightarrow \mu^+\mu^-\gamma$ events to calculate the efficiency of the pixel veto
- Pixel Seed Veto Scale Factor $= 0.998 \pm 0.013$

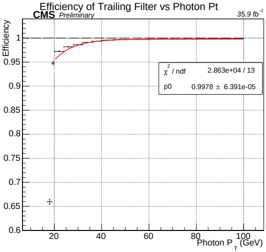
Require two photons in the final state, two factors of both values are used.

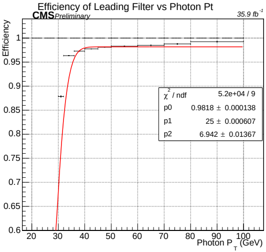
MET filters

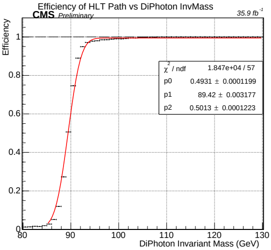
- ⋆ Primary Vertex filter
- ⋆ Beam Halo Filter
- ⋆ HBHE nose filter
- ⋆ HBHEiso noise filter
- ⋆ ECAL trigger primitive filter
- ⋆ ee badSC noise filter
- ⋆ Bad PF muon filter
- ⋆ Bad charged hadron filter
- ⋆ Dublicate muon filter

Trigger Efficiencies

- measured using a tag and probe method
- control trigger: *HLT_Ele27_WPTight_Gsf*
- calculate the leading and subleading efficiencies
- calculate the efficency with respect to the invariant mass cut







Overall the trigger is 97.2 % efficient.