Search for supersymmetry in events with photons and missing transverse energy

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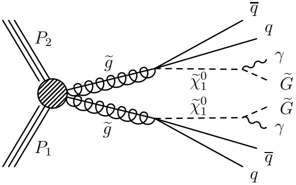
Analysis Overview

Search for General gauged mediated (GGM) supersymmetry breaking in final state involving photons. The data sample corresponds to an integrated luminosity of 2.32 fb^{-1} of proton proton collisions at $\sqrt{s} = 13\,TeV$ was collected with the CMS detector at the LHC in 2015.

GGM supersymmetry breaking can produce events with double photons, jets and significant missing energy (E_T^{miss}).



We assume gluino pair production where the NLSP neutralino decays to a gravitino and photon ($\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$), resulting in characteristic events with jets, two photons and large E_T^{miss}

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

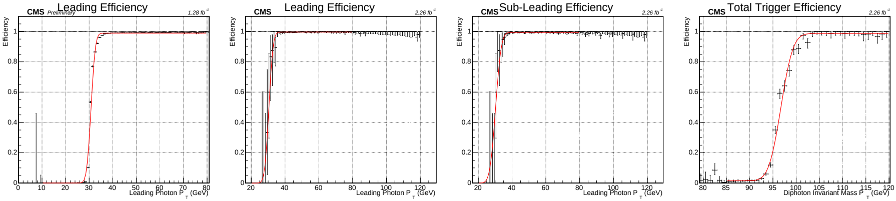
Other backgrounds-small and studied with Monte Carlo (MC).

- $Z\gamma\gamma \rightarrow \nu\nu\gamma\gamma$
- $W\gamma\gamma \rightarrow l\nu\gamma\gamma$
- $t\bar{t}\gamma\gamma$

Trigger

Primary analysis trigger:
HLT_Diphoton30_18_R9Id_OR_IsoCaloId_AND_HE_R9Id_Mass95

- Lead Photon $P_T > 30 GeV$ and trail for photon $P_T > 18 GeV$
- $M_{\gamma\gamma} > 95 GeV$



HLT efficiency is calculated by a tag and probe method and is 98.6% for photon $P_T > 40 GeV$
Trigger requires two photons passing the sub-leading filter and one photon passing the leading filter, so that the total efficiency $\epsilon_{tot} = \epsilon_{lead,lead} \times \epsilon_{lead,sub} \times \epsilon_{sub,sub}$

Object Selection

Muons

- $P_T > 30 GeV$
- $|\eta| < 1.4442$
- Passes medium muon ID
- Passes loose muon isolation

Electrons

- From PF photon collection
- $P_T > 40 GeV$
- $|\eta| < 1.4442$
- Passes medium photon ID
- Fails pixel seed veto
- Remove electrons that overlap within $\Delta R < 0.4$ of a muon

Photons

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

Jets

- $P_T > 30 GeV$
- $|\eta| < 2.4$
- Passes PF Loose ID
- Remove jets that overlap within $\Delta R < 0.4$ of a muon, electron, or a photon

Fake Selection

‘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 $\sigma_{i\eta i\eta}$ requirements of the medium photon ID.
  ($1.33GeV <$ charged hadron isolation $< 15GeV$ XOR $0.0102 < \sigma_{i\eta i\eta} < 0.0150$)

Events are sourted int four categories depending on the selection of their hightest-p_T electromagnetic objects:

- $\gamma\gamma$
- ee
- ff
- $e\gamma$

Control and Candidate Sample

Double electron Sample (ee)

- Used to model EM objects in the QCD background
- Require $75 GeV < m_{ee} < 105 GeV$ to collect $Z \rightarrow ee$ events
- Require $\Delta R > 0.3$ between electrons

Double fake sample (ff)

- Passes the primary trigger
- Used to model EM objects in the QCD background
- require $m_{ff} > 105 GeV$
- require $\Delta R > 0.3$ between fakes.

Candidate DiPhoton Sample ($\gamma\gamma$)

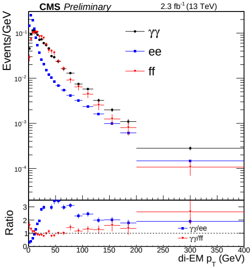
- passes primary trigger
- Require $m_{\gamma\gamma} > 105 GeV$
- $\Delta R > 0.3$ between photons

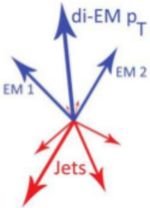
Signal Region is $E_T^{miss} > 100 GeV$

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

Strategy

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

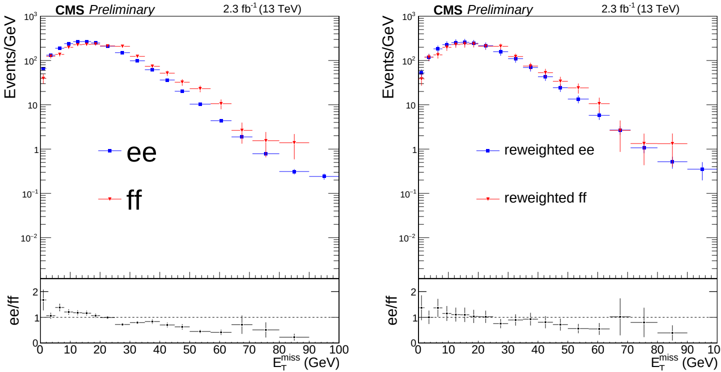




- Model the hadronic recoil of the event with the di-EM p_T of the event, where di-EM p_T is the vector sum of the P_T of the two electromagnetic object.
- Reweight the control samples to correct for the differences in hadronic activity.

Reweight E_T^{miss} backgrounds

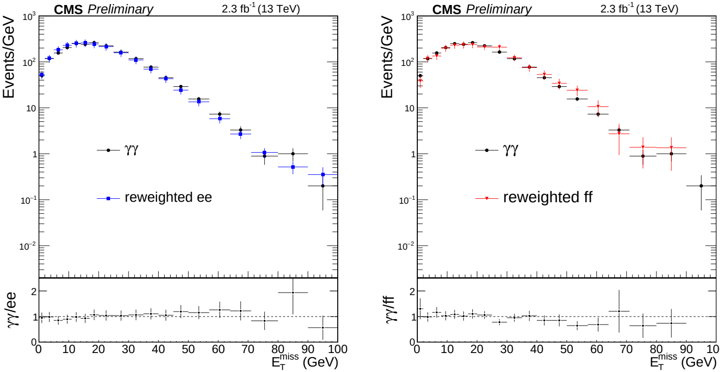
Unweighted (left) and di-EM p_T reweighted (right) E_T^{miss} distributions of the ee and ff samples



Samples are normalized to $E_T^{miss} < 50$ GeV of the $\gamma\gamma$ (signal contamination $< 1\%$)

Comparison to Candidate $\gamma\gamma$ Sample

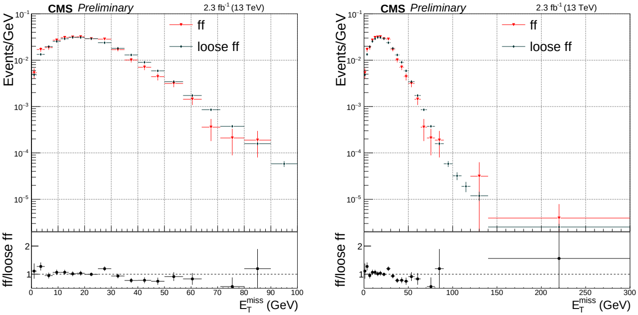
Comparing the candidate E_T^{miss} distribution to the distributions for the ee (left) and ff (right) control samples.



Samples are normalized to $E_T^{miss} < 50$ GeV of the $\gamma\gamma$

Estimation of pure QCD background

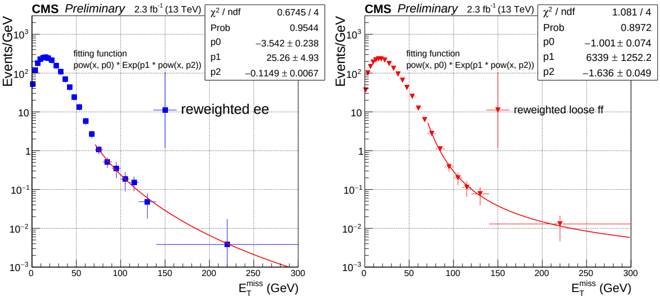
- The primary background estimate comes from the double electron sample.
- We use the prediction from double fake as a systematic uncertainty on the estimate from the ee sample.
- Low statistics from ff sample in E_T^{miss} >100 GeV signal region.



- Tight fake and loose fake samples match well in $E_T^{miss} < 100\ GeV$ region.
- Loose fake samples can be used to model the shape in high E_T^{miss} region.
- Determine ff sample in signal region from looser fake definition.

Systematic Uncertainty from Shape Difference

- Fit reweighted ee and loose ff samples for $70\ GeV < E_T^{miss} < 300$ GeV with a function $\chi^{p0} exp(p1\chi^{p2})$ with fit parameters p0, p1, p2
- Integrate fits in each E_T^{miss} bin for $E_T^{miss} > 100$ GeV.
- Difference between ee and loose ff result gives shape uncertainties in that bin.
- Largest uncertainty in the last bin due to the large bin width.



Final QCD Estimate

E_T^{miss} (GeV)	Bkg Prediction
100-110	1.85 ± 0.96
110-120	1.53 ± 0.63
120-140	0.97 ± 0.62
> 140	0.61 ± 2.15

- Di-EMp_T reweighting uncertainty comes from propagating toy Di-EMp_T plots to the reweighted E_T^{miss} distribution.
- Additional systematic comes from the differences between reweighting with the di-EM p_T only and reweighting with di-EM p_T and jet multiplicity.

E_T^{miss} (GeV)	Systematic Uncertainty	Value (%)
100-110	Di-EM p_T reweighting	15.11
	Jet multiplicity reweighting	33.77
	Shape difference between ee and ff	18.18
	Statistical uncertainty of ee sample	30.81
110-120	Di-EM p_T reweighting	16.60
	Jet multiplicity reweighting	14.87
	Shape difference between ee and ff	12.07
	Statistical uncertainty of ee sample	33.33
120-140	Di-EM p_T reweighting	33.31
	Jet multiplicity reweighting	29.39
	Shape difference between ee and ff	14.40
	Statistical uncertainty of ee sample	41.75
> 140	Di-EM p_T reweighting	39.75
	Jet multiplicity reweighting	20.34
	Shape difference between ee and ff	150.36
	Statistical uncertainty of ee sample	70.98

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

- Calculate the ratio of the electrons faking photons, $f_{e\to\gamma}$ using the $Z \to ee$ invariant mass peak in both an ee sample and an $e\gamma$ sample.
- To get the final EWK background estimate, we weight the $e\gamma E_T^{miss}$ distribution by $f_{e\to\gamma}/(1 - f_{e\to\gamma})$ to get the number of $e\gamma$ events that sneak into the candidate $\gamma\gamma$ sample.

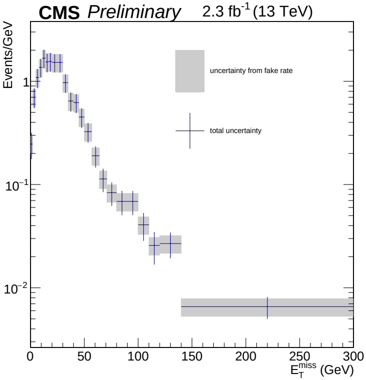
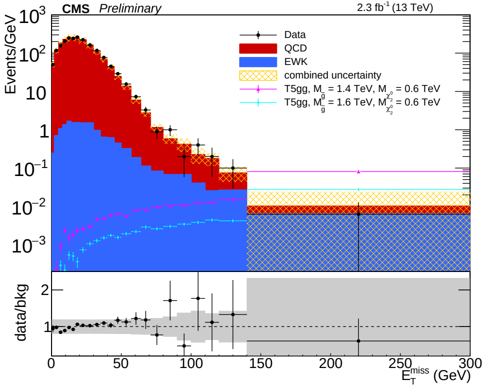


Table: Estimation of total EWK background for $E_T^{miss} > 100$ GeV

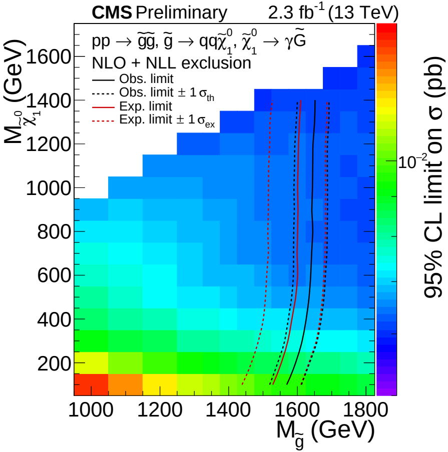
$E_T^{miss} bin$ (GeV)	Expected
$100 - 110$	0.11 ± 0.09
$110 - 120$	0.07 ± 0.06
$120 - 140$	0.14 ± 0.11
$140 - Inf$	0.27 ± 0.22

Observed vs Expected

E_T^{miss} (GeV)	Expected	Observed
100-110	2.26 ± 0.96	4
110-120	1.79 ± 0.64	2
120-140	1.51 ± 0.64	2
> 140	1.64 ± 2.16	1



Limits



- An expected exclusion reach for the analysis was done using the modified frequentist CLs methods
- This is based on long-likelihood test statistic that compares the likelihood of the SM-only hypothesis to the likelihood of the presence of signal in addition to the SM conditions
- The likelihood functions are based on the expected shape of the E_T^{miss} distribution for signal and background in four separate bins.
- For typical values of neutralino mass, we expect to exclude gluino masses out of 1.5 TeV, improving the reach of previous searches performed at center-of-mass energies of 8 TeV.

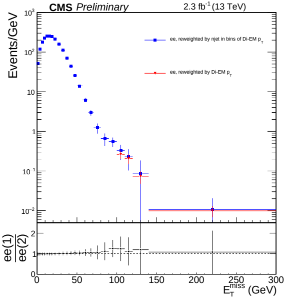
Conclusions

- Full analysis has been done on 13 TeV data
- Even with $2.3 fb^{-1}$ of data, we are able to extend our reach from 8TeV analysis
- No evidence of SUSY seen, but we expect to probe even higher mass scales this year with a larger dataset.

Back Up

Jet multiplicity Reweighting

The difference in jet multiplicity between the candidate sample and the control sample can also affect the overall E_T^{miss} resolution of the background estimation .
The jet multiplicity distribution for the candidate and the ff samples are similar, but the candidate and ee are different.
To investigate the effect of jet multiplicity reweighting, we plotted the eeE_T^{miss} ditribution reweighting by the jet multiplicity in bins of di-EMp_T.



The difference bewtween them is small.
Choose not to reweight by the jet multiplicity, but we take the difeerence as a systematic uncertainty.

Contributions to control samples

There is a small Contribution to the ee control sample from $t\bar{t}$ events and the contribution to the ff sample from $Z \rightarrow \nu\bar{\nu}$

$t\bar{t}$ events will contribute 17.27 ± 0.98. and $Z \rightarrow \nu\bar{\nu}$ contribution is almost negligible. To get rid of the contamination we substract the shape of $t\bar{t}$ from our ee control sample.