Chapter 1

Data Analysis

The signature of GGM SUSY particle production in this search is an excess of two-photon events with high $\not\!\!E_T$. $\not\!\!E_T$ is reconstructed using the particle flow algorithm as described in Sec. **??**. Candidate two-photon events, as well as control events, are selected according to the offline object criteria presented in Secs. **??** and **??**, the event quality criteria in Sec. **??**, and the trigger requirements in Sec. **??**. These are summarized in Table 1.1.

Table 1.1: Selection criteria for $\gamma\gamma$, $e\gamma$, ee, and $f\!f$ events.

Variable	Cut			
	$\gamma\gamma$	$e\gamma$	ee	$f\!f$
HLT match	IsoVL	IsoVL	IsoVL	IsoVL || R9Id
E_T	$> 40/$ > 25 GeV	$> 40/$ > 25 GeV	$> 40/$ > 25 GeV	$> 40/$ > 25 GeV
SC $\|\eta\|$	< 1.4442	< 1.4442	< 1.4442	< 1.4442
H/E	< 0.05	< 0.05	< 0.05	< 0.05
$R9$	< 1	< 1	< 1	< 1
Pixel seed	No/No	Yes/No	Yes/Yes	No/No
I_{comb}, $\sigma_{i\eta i\eta}$	< 6 GeV && < 0.011	< 6 GeV && < 0.011	< 6 GeV && < 0.011	< 20 GeV && (≥ 6 GeV || ≥ 0.011)
JSON	Yes	Yes	Yes	Yes
No. good PVs	≥ 1	≥ 1	≥ 1	≥ 1
ΔR_{EM}	> 0.6	> 0.6	> 0.6	> 0.6
$\Delta\phi_{EM}$	≥ 0.05	≥ 0.05	≥ 0.05	≥ 0.05

This search utilizes 4.7 fb^{-1} of CMS data collected during the period April-December 2011, corresponding to the following datasets [?]:

- `/Photon/Run2011A-05Jul2011ReReco-ECAL-v1/AOD`
- `/Photon/Run2011A-05Aug2011-v1/AOD`
- `/Photon/Run2011A-03Oct2011-v1/AOD`
- `/Photon/Run2011B-PromptReco-v1/AOD`

The search strategy is to model the backgrounds to the GGM SUSY signal using $\not\!\!E_T$ shape templates derived from the control samples, and then to look for a high-$\not\!\!E_T$ excess above the estimated background in the $\gamma\gamma$ sample. There are two categories of backgrounds: QCD processes with no real $\not\!\!E_T$ and electroweak processes with real $\not\!\!E_T$ from neutrinos. The relevant QCD background processes are multijet production with at least two jets faking photons, photon + jet production with at least one jet faking a photon, diphoton production, and Z production with a radiated photon where at least one of the Z decay products (typically a jet) fakes a photon. The relevant electroweak background processes, which are small compared to the QCD background, involve $W \to e\nu$ decay with a recoiling jet that fakes a photon or a real radiated photon. In both cases, the electron is misidentified as a photon due to a small inefficiency in reconstructing the electron pixel seed. The main diagrams contributing to the QCD(electroweak) backgrounds are shown in Figure **??**(**??**). **Generate these Feynman diagrams.**

Figure **??** shows the $\not\!\!E_T$ spectrum of the $\gamma\gamma$ search data sample overlaid on the $\not\!\!E_T$ spectra of MC simulated background components. The MC spectra are normalized to the integrated luminosity of the $\gamma\gamma$ data sample. **Make this plot.** The dominant background components are QCD inclusive photon processes. The MC is not used in the actual background estimation. It is just shown here to illustrate the breakdown of backgrounds.

Data control samples are used to model all of the backgrounds. The primary control sample used to model the QCD background is the *ff* sample, which is similar to the candidate $\gamma\gamma$ sample but with combined isolation or $\sigma_{i\eta i\eta}$ cuts inverted. The cuts on these variables are used to distinguish between photons and jets, so by inverting those cuts, the resulting *ff* sample becomes enriched with QCD dijets. Because the fake photons are still required to pass a tight cut on H/E, they are guaranteed to be very electromagnetic jets, with an EM energy scale and resolution similar to that of the candidate photons. This insures that the resulting estimate of the $\not\!\!E_T$ shape does not have too long of a tail from severe HCAL mis-measurements that are actually rare in the $\gamma\gamma$ sample, as shown in Figure **??**. **Plot the $\gamma\gamma/ff$ $\not\!\!E_T$ agreement for different values of the ff H/E cut in MC. Make the same plot in data for a restricted $\not\!\!E_T$ range?**

As a cross-check, the *ee* sample is also used to model the QCD background. This sample of Z decays should have no true $\not\!\!E_T$, just like the *ff* sample, and the electron definition (differing from the photon definition only in the presence of a pixel seed) insures that the electron energy scale and resolution is similar to that of the photon.

Finally, the $e\gamma$ sample is used to model the electroweak background from $W \to e\nu$ decays. The $e\gamma$ $\not\!\!E_T$ distribution is scaled by the electron→photon misidentification rate to predict the number of $W\gamma$ and W + jet events in the $\gamma\gamma$ sample.

1.1 Modeling the QCD Background

1.1.1 Systematic Errors

Jet Energy Scale Uncertainty

The dijet $\mathrm{p_T}$ reweighting method utilizes jets corrected for imperfect calorimeter response (see Sec. **??** for a description of the jet reconstruction and correction procedure). Since the applied jet energy scale (JES) factor has an error associated to it due to the limitations of the JES derivation ([?] and Sec. ??), this uncertainty must be propagated to the uncertainty on the dijet p_T weights.

The JES contribution to the dijet p_T weights is estimated by performing 1000 pseudo-experiments on each of the $\gamma\gamma$ and ff samples. For the purpose of estimating the JES error, the results of the true experiment may be thought of as a set of measurements:

- The set of **uncorrected jet 4-vectors** corresponding to the **leading EM object** in the $\gamma\gamma$ sample $\left\{p_{j1}^{\mu 1}, p_{j1}^{\mu 2}, ..., p_{j1}^{\mu N_{\gamma\gamma}}\right\}$
- The set of **uncorrected jet 4-vectors** corresponding to the **trailing EM object** in the $\gamma\gamma$ sample $\left\{p_{j2}^{\mu 1}, p_{j2}^{\mu 2}, ..., p_{j2}^{\mu N_{\gamma\gamma}}\right\}$
- The set of **JES** accompanying the uncorrected jet 4-vectors corresponding to the **leading EM object** in the $\gamma\gamma$ sample $\left\{c_{j1}^{1}, c_{j1}^{2}, ..., c_{j1}^{N_{\gamma\gamma}}\right\}$
- The set of **JES** accompanying the uncorrected jet 4-vectors corresponding to the **trailing EM object** in the $\gamma\gamma$ sample $\left\{c_{j2}^{1}, c_{j2}^{2}, ..., c_{j2}^{N_{\gamma\gamma}}\right\}$
- The set of **JES uncertainties** accompanying the uncorrected jet 4-vectors corresponding to the **leading EM object** in the $\gamma\gamma$ sample $\left\{\sigma_{cj1}^{1}, \sigma_{cj1}^{2}, ..., \sigma_{cj1}^{N_{\gamma\gamma}}\right\}$
- The set of **JES uncertainties** accompanying the uncorrected jet 4-vectors corresponding to the **trailing EM object** in the $\gamma\gamma$ sample $\left\{\sigma_{cj2}^{1}, \sigma_{cj2}^{2}, ..., \sigma_{cj2}^{N_{\gamma\gamma}}\right\}$
- The set of **uncorrected jet 4-vectors** corresponding to the **leading EM object** in the ff sample $\left\{p_{j1}^{\mu 1}, p_{j1}^{\mu 2}, ..., p_{j1}^{\mu N_{ff}}\right\}$
- The set of **uncorrected jet 4-vectors** corresponding to the **trailing EM object** in the ff sample $\left\{p_{j2}^{\mu 1}, p_{j2}^{\mu 2}, ..., p_{j2}^{\mu N_{ff}}\right\}$

- The set of **JES** accompanying the uncorrected jet 4-vectors corresponding to the **leading EM object** in the ff sample $\left\{c_{j1}^{1}, c_{j1}^{2}, ..., c_{j1}^{N_{ff}}\right\}$
- The set of **JES** accompanying the uncorrected jet 4-vectors corresponding to the **trailing EM object** in the ff sample $\left\{c_{j2}^{1}, c_{j2}^{2}, ..., c_{j2}^{N_{ff}}\right\}$
- The set of **JES uncertainties** accompanying the uncorrected jet 4-vectors corresponding to the **leading EM object** in the ff sample $\left\{\sigma_{cj1}^{1}, \sigma_{cj1}^{2}, ..., \sigma_{cj1}^{N_{ff}}\right\}$
- The set of **JES uncertainties** accompanying the uncorrected jet 4-vectors corresponding to the **trailing EM object** in the ff sample $\left\{\sigma_{cj2}^{1}, \sigma_{cj2}^{2}, ..., \sigma_{cj2}^{N_{ff}}\right\}$

From these measurements, the $\gamma\gamma$ and ff dijet p_T spectra and the resulting ff dijet weights can be calculated. In each of the 1000 pseudo-experiments, a new set of JES factors is generated according to the measured JES uncertainties, and new dijet p_T spectra and weights are subsequently calculated. The spread of the 1000 weights (binned in dijet p_T) is taken as the error due to JES uncertainty. The total error on the weights is the quadrature sum of the JES error and the statistical error, and is propagated to the error on the final $\not\!\!E_T$ measurement via a similar pseudo-experiment procedure described in Sec. 1.1.1.[1]

If the JES uncertainty were to cause the jet energy to be reconstructed below the 20 GeV ntuple cut, there could be a small error or bias in the $\not\!\!E_T$ introduced due to EM-matched jets falling below the matching threshold. The percentage of jets lost due to jet E_T matching threshold has been checked in data, and found to be X% (X% of events). Furthermore, the trailing EM E_T cut is 25 GeV/c, implying that the JES would have to be mis-measured by at least 20% to fall below the jet matching threshold. Since the typical JES uncertainty is no more than 5%, a mis-measurement of this type is a 4σ event and should occur in only 0.1% of cases. As expected, this effect is negligible, as shown in Figure X.

[1]The $\not\!\!E_T$ is uncorrected and therefore its central value per event is unaffected by a change in the JES.

Statistical Uncertainty in the ff or ee Weights

1.2 Modeling the Electroweak Background

1.3 Results

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