DESY Summer Student Program

Contribution from W/Z + one/two photon production in $\gamma\gamma + E_T^{miss}$ final state

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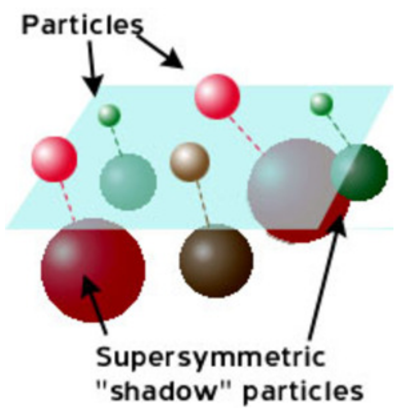
Abstract

A search for supersymmetry is presented using a production of diphoton ($\gamma\gamma$) events with two prompt photons and large missing transverse energy (E_T^{miss}). The search uses a data sample of proton-proton (pp) collisions at a center-of-mass energy of $\sqrt{s} = 7TeV$, corresponding to luminosity of $\int Ldt = 1fb^{-1}$, collected with the ATLAS detector. Several variables that are expected to provide discriminating power are compared between data and gauge-mediated SUSY breaking model predictions. The backgrounds from the W/Z production with the associated electroweak production of two photons are studied. Different (E_T^{miss}) reconstruction algorithms are compared.

Contents

1. Introduction

The goal of particle physics has been to identify what appear to be structureless units of matter and to understand the nature of the forces acting between them. Several basic constituents of matter are known so far: six quarks and six leptons. They have spin 1/2 and are called fermions. There are four types of forces acting between them: electromagnetic, weak, strong and gravitational. The first three are mediated by the so called bosons, i.e. particles with spin 1: the photon, W/Z bosons and the gluon. As quarks and leptons, they are also believed to be structureless. A theory describing the three forces is called Standard Model (SM) and is based on the so called gauge theories. It is very well tested experimentally and no significant deviations are found so far.
However there are many indications that SM is not the ultimate theory of Nature. They include, for example, the hierarchy problem, the possible existence of dark matter and dark energy. Moreover, SM does not describe gravity.
Many extensions of SM have been proposed. One of the best motivated theory is the so-called Supersymmetry (SUSY). It introduces the symmetry between fermions and bosons, hence predicts a bosonic partner for each fermion and vice versa. SUSY can solve many current problems of SM, e.g. it might provide a candidate for particle, that constitutes the dark matter.



If SUSY is realized in Nature, there is a multitude of new particles that we can discover at the Large Hadron Collider (LHC). SUSY particles are produced in the strong interaction at the LHC which leads to large expected event yields. As a consequence, there is a good chance that SUSY will be one of the first new-physics signals at the LHC.
This work is related to a search of SUSY at the LHC. A particular model is considered: gauge-mediated SUSY breaking (GMSB). It is expected to manifest itself via two photons and missing transverse energy in the final state. However, there are many SM processes that also lead to this signature. These processes include for example:

$$\begin{cases} pp \to Z(\to \nu\nu) + \gamma\gamma \\ pp \to W(\to \nu + lepton) + \gamma\gamma \\ pp \to W(\to \nu + electron) + \gamma \end{cases}$$

(where the electron misidentified as a photon in the last process).
Obviously these processes also have two reconstructed photons and missing energy (E_T^{miss}). In order to discover SUSY or set the limit, the backgrounds of this kind must be well under control. It is the main goal of this work to study some of the background processes to the SUSY search in diphoton + E_T^{miss} final state. In particular, associated production of W or Z bosons with two photons is considered.

2. Theory

2.1. Supersymmetry

Supersymmetry (SUSY) introduces a symmetry between fermions and bosons, resulting in a SUSY partner with identical quantum numbers for each SM particle. At the Large Hadron Collider (LHC), the dominant SUSY process would be the production of pairs of SUSY partners of quarks (squarks) or gluons (gluinos) via the strong interaction. These would then decay through cascades involving other sparticles until the lightest SUSY particle (LSP) is produced [1]. Assuming R-parity conservation, the LSP is stable and escapes detection. No SUSY partners of SM particles have been observed yet, indicating that SUSY must be broken to decouple the masses of the SM particles and their SUSY partners. In gauge-mediated SUSY breaking (GMSB) models the LSP is the gravitino $\widetilde{G}$. GMSB experimental signatures are largely determined by the character of the next-to-lightest SUSY particle (NLSP), which for most of the GMSB parameter space is the lightest neutralino $\widetilde{\chi_1^0}$. Should this neutralino be the SUSY partner of the U(1) gauge boson (the "bino"), the final decay in the cascade is dominated by $\widetilde{\chi_1^0} \rightarrow \gamma\widetilde{G}$, with two cascades per event, leading to a final state $\gamma\gamma + (E_T^{miss}) + X$, where E_T^{miss} results from the escaping gravitinos and X represents SM particles emitted in the prompt cascade decays.

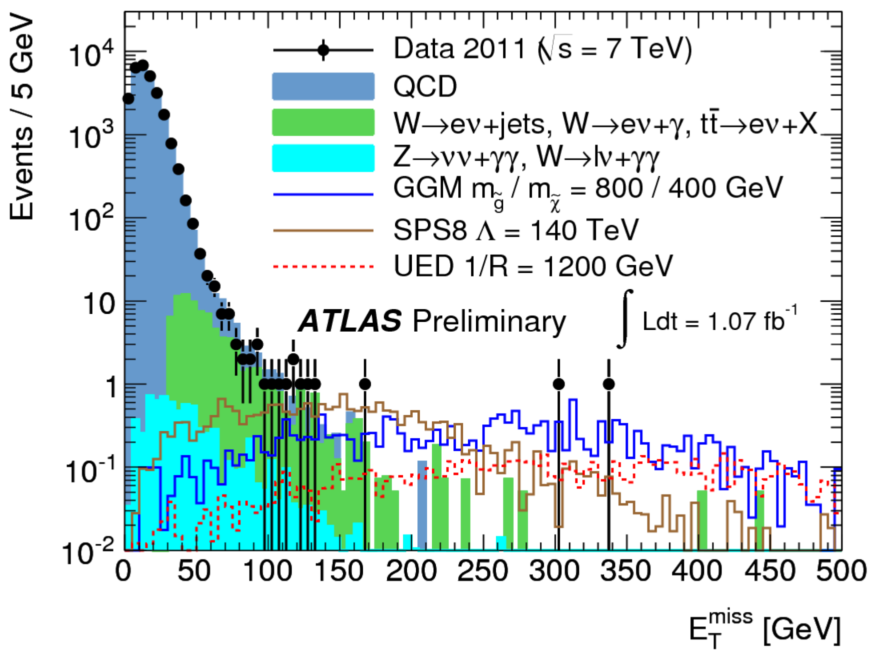


Figure 1: E_T^{miss} spectrum of the $\gamma\gamma$ candidates

2.2. Background sources

The SM processes that give rise to events with large E_T^{miss} and two photons in the final state can be grouped into two primary components and estimated with dedicated control samples. The first of these components, referred to as QCD background, arises from a mixture of SM processes that include $\gamma\gamma$ production as well as $\gamma + jet$ and multijet events with at least one jet misidentified as a photon [1]. The QCD background is the dominant source of observed $\gamma\gamma$ events at low E_T^{miss} and its spectrum, which contains a mixture of events with zero, one or two prompt photons, is expected to lie between the spectra from the QCD_γ and $Z \rightarrow ee$ control samples. The E_T^{miss} spectrum of the QCD_γ control sample, which provides the best description of the E_T^{miss} spectrum at low E_T^{miss}, was chosen to model the composite QCD background. The difference between this estimate and derived

from the $Z \to ee$ template was used to provide an estimate of the systematic uncertainty on the resulting background prediction.
The second background component is due to $W + X$ and $t\bar{t}$ events, for which final-state neutrinos produce significant (E_T^{miss}). These can pass the selection if an electron from the W or t-quark decay is misidentified as a photon and the second photon is either a real photon ($W\gamma$) events), a jet faking a photon (W + jets events), or a jet or second electron faking a photon ($t\bar{t}$ events). The background contribution, from W + X and $t\bar{t}$ events, was estimated via an "electron-photon" control sample composed of events with both a photon and an electron with $E_T > 20GeV$ and scaled by the probability for an electron to be misidentified as a tight photon, as determined from the $Z \to ee$ sample.

2.3. $W\gamma\gamma$ production

Precise and reliable predictions of cross sections at hadron colliders require the calculation of higher order corrections.
Corrections for processes with two photons and one W in the final state [2], namely the production of

$$\begin{cases} "W^+\gamma\gamma" pp, p\bar{p} \to \nu_l l^+ \gamma\gamma + X \\ "W^-\gamma\gamma" pp, p\bar{p} \to l^+ \nu_l l \overline{\gamma}\gamma + X \end{cases}$$

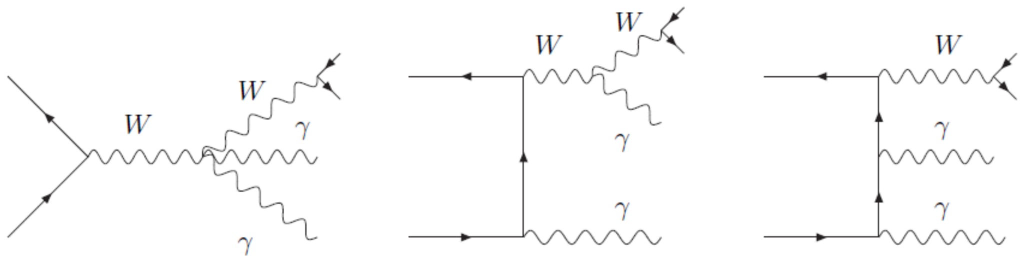


Figure 2: Examples of Feynman diagrams - three topologies of contributing to the process $pp \to W^{+/-}\gamma\gamma + X$ at tree-level.

Guided by the procedure developed in Ref.[2] we can observed this processes also use Feynman diagrams Figure 2.
For the calculation of virtual corrections, it is convenient to classify the contributing Feynman graphs according to the number of electroweak boson vertexes which are attached to the quark lines. It is important for our analysis to consider W and Z bosons, as product of their decay neutrino creates E_T^{miss}.

2.4. $Z\gamma\gamma$ production

The calculation of the next-to-leading-order (NLO) QCD corrections to Z-boson production in association with two photons including off-shell effects for two decay modes

$$Z\gamma\gamma = \begin{cases} pp, p\bar{p} \to Z\gamma\gamma + X \to l^+ l^- \gamma\gamma + X \\ pp, p\bar{p} \to Z\gamma\gamma + X \to \overline{\nu}\nu\gamma\gamma + X \end{cases}$$

Both processes provide background for new-physics searches [3]. The process with its signature of two photons and missing transverse energy appears for example as background in models with gauge-mediated supersymmetry breaking (GMSB). In Figure 3 we can see examples of topologies of Feynman diagrams contributing to the different process at tree level.

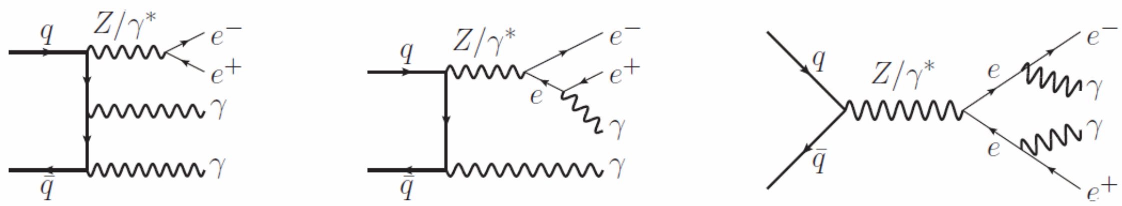


Figure 3: Examples of topologies of Feynman diagrams contributing to the different process at tree level. Top-row: $pp \to Z\gamma\gamma + X$ including Z decays into a pair of charged leptons.

2.5. Next-to-leading order (NLO) correction

The next-to-leading order (NLO) real emission contribution to the hadronic cross section, however, can probe new partonic initial states not present at leading order (LO), so that the LO scale uncertainty can sometimes be totally misleading. This is especially true for processes which are characterized by a QCD singlet final state at LO [4]. For these the large correction $K = \sigma^{NLO}/\sigma^{LO} \sim 1.8$ does not signal a breakdown of pertubation theory, but strongly asks for perturbutive improvements of the one-jet-inclusive cross sections as a major contribution to the full next-to-next-to-leading order cross sections.

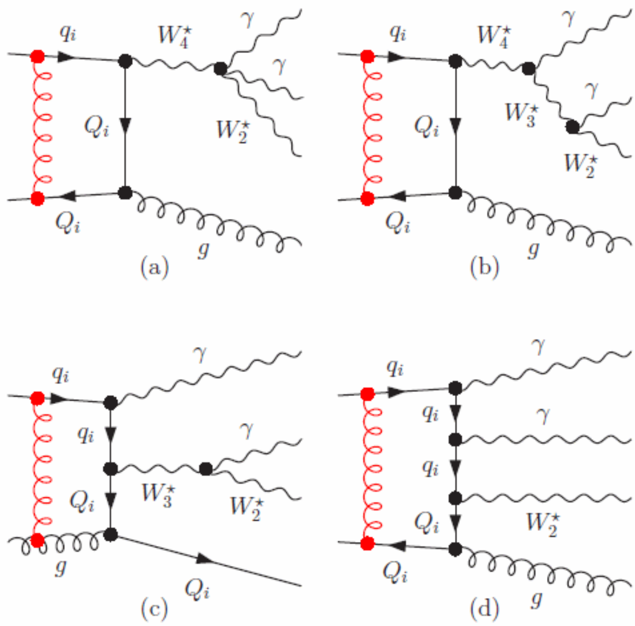


Figure 4: Selected topologies contributing to $W^-\gamma\gamma + jet$ production at NLO

3. Measurement

3.1. Comparison of Data and SUSY GGM model distributions

In this section we compare several distributions between data and SUSY GGM model. In the latter, the full mass spectrum and the gluino branching ratios and decay widths were calculated for a range of gluino and neutralino masses.

Figure 5 shows the number of reconstructed photons and transverse momentum of the photons. The p_T shapes are very different - SUSY predicts much harder spectrum. In Figure 6 the same quantities are shown for the jets. Again, SUSY predicts much harder spectrum and higher jet multiplicities.

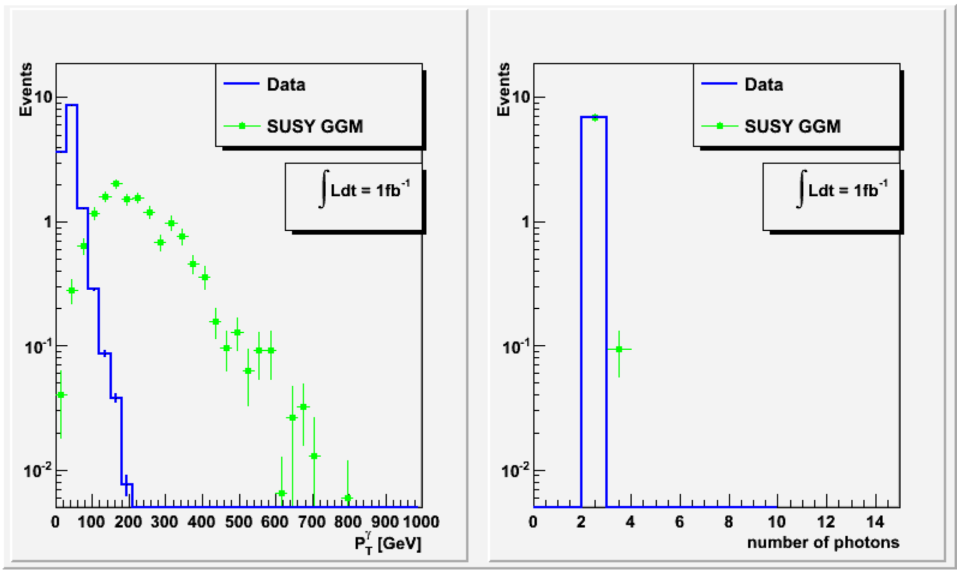


Figure 5: Distributions of the transverse momentum and multiplicity of photons for SUSY GGM signal (green dots) are compared to data (blue line)

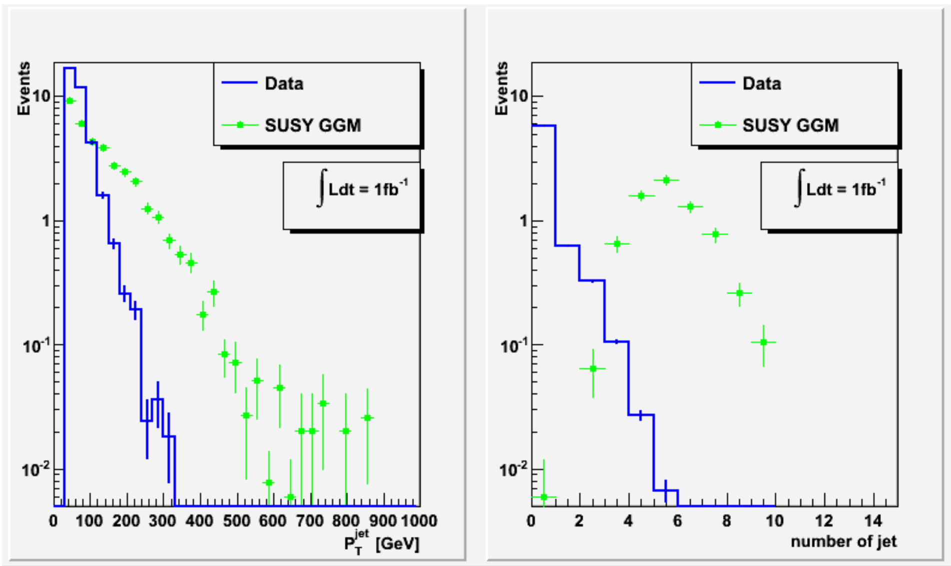


Figure 6: Distributions of the transverse momentum and multiplicity of jets for SUSY GGM signal (green dots) are compared to data (blue line)

In Figure 7 E_T^{miss} distributions are shown.

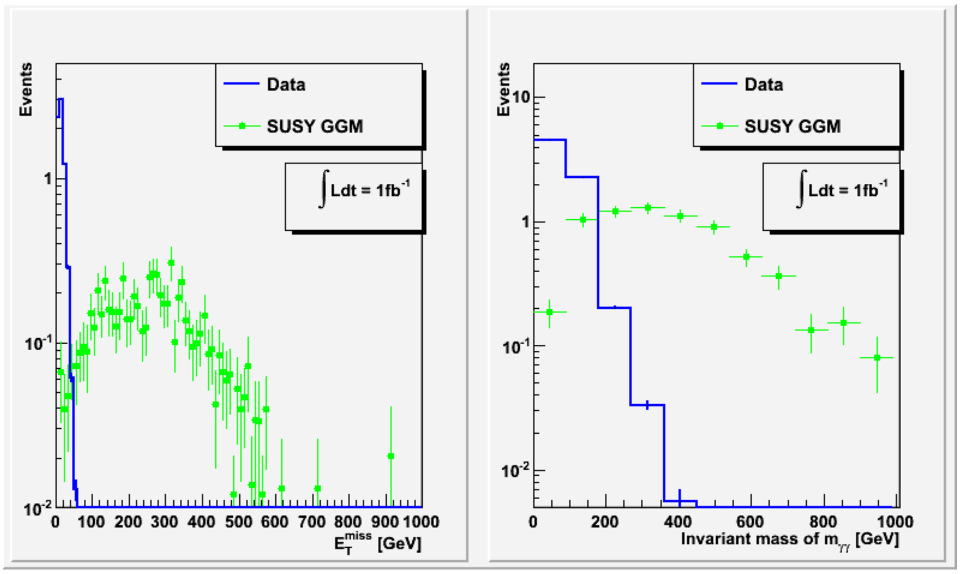


Figure 7: Distributions of the E_T^{miss} and invariant mass distribution of two photons for SUSY GGM signal (green dots) are compared to data (blue line)

3.2. Comparison of missing transverse energy reconstruction algorithms

There are several algorithms for E_T^{miss} reconstruction available in ATLAS. In this section we compare their performance.

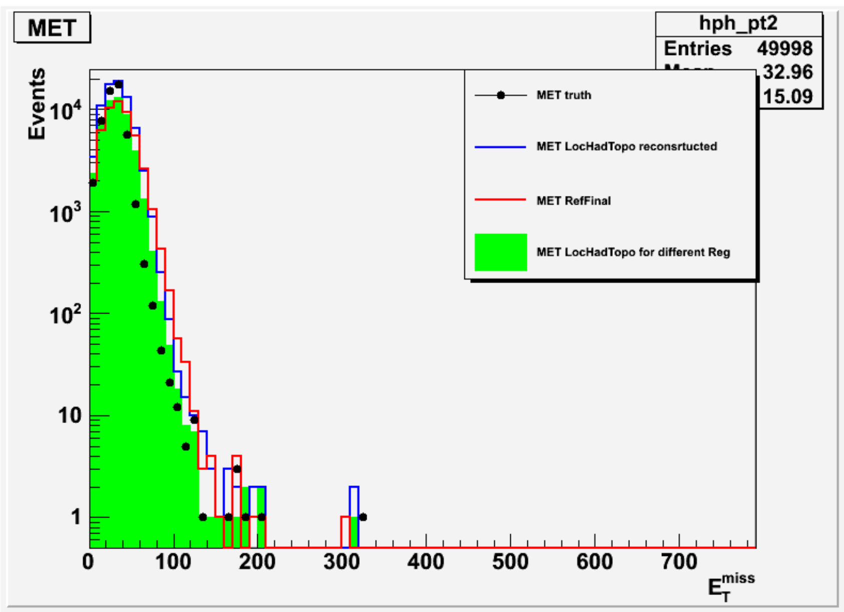


Figure 8: E_T^{miss} (in GeV) spectra of the $\gamma\gamma$ candidate events reconstructed with different methods.

In Figure 8 E_T^{miss} distributions reconstructed with different methods are shown. The true value from the Monte Carlo simulation is also shown. It can be concluded that LocHadTopo is slightly preferred over others.

3.3. Distance in the eta-phi variables

For $W\gamma$ and $Z\gamma$ distributions we are looking for distance in the eta-phi variables. Using a formula $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ The analyzed sample consists of 1000 events generated by the Monte Carlo. We need to do these calculations to evaluate the simulated data. If distance beatween reconstructed and truth data for electron or for photon will be less than 0.2 ($\Delta R(el, ph) < 0.2$). This indicates good performance of the detector. Also if these distanse is less than 0.01 ($\Delta R(el, ph) < 0.01$) electron misidentified as photon. In Figure 9 we observe a small distance between reconstructed and simulated

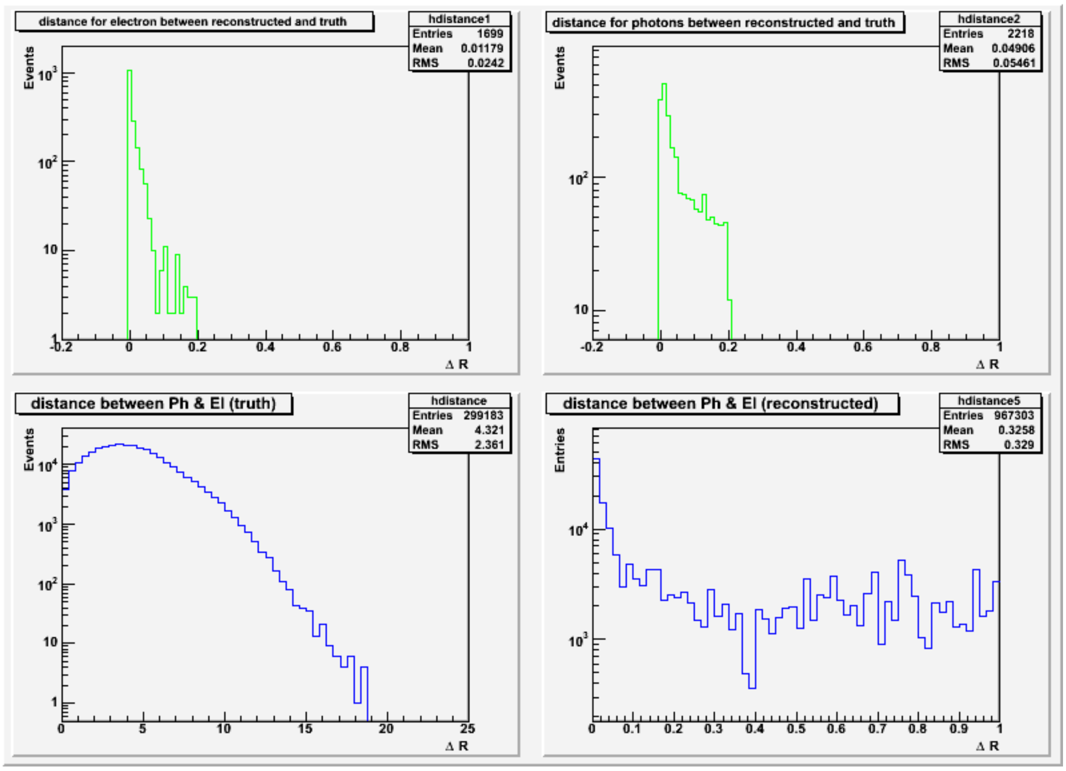


Figure 9: Distance in the eta-phi variables for $W\gamma$ MC simulation

photon and electron as a resalt it shows good performance of the detector.
In Figure 10 we also observe a small distance between reconstructed and simulated photon and electron which shows good performance of the detector.

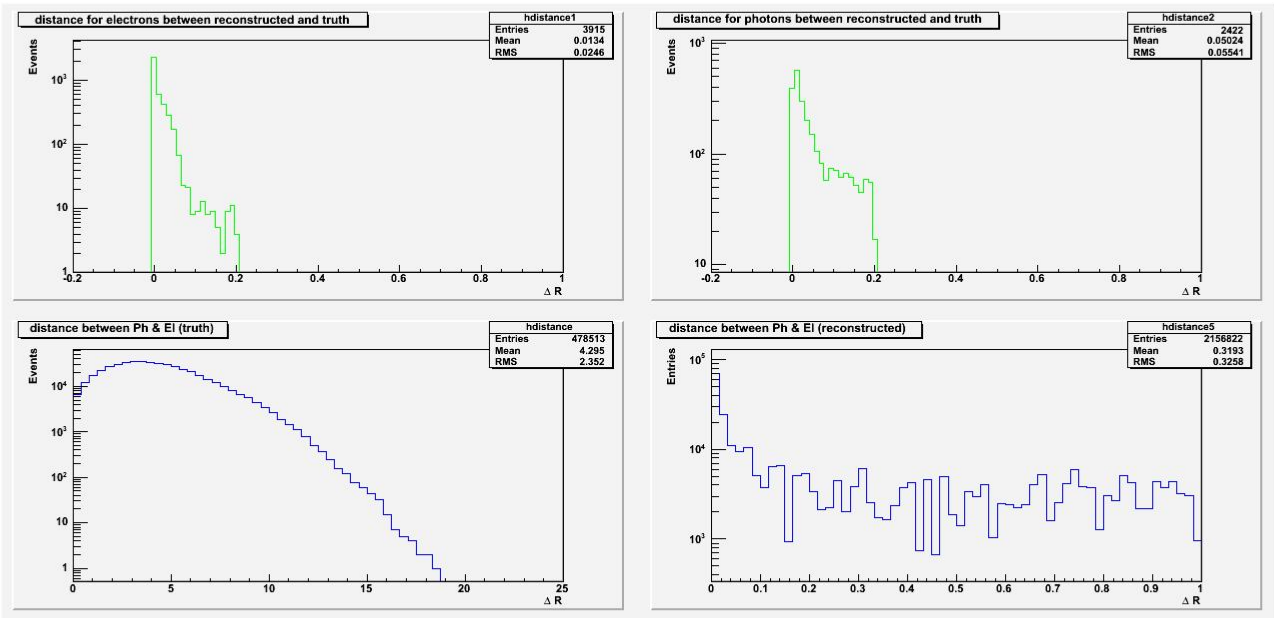


Figure 10: Distance in the eta-phi variables for $Z\gamma$ MC simulation

In this section we compare several distributions for (E_T^{miss}) and P_T between W^+ W^- Z bosons.

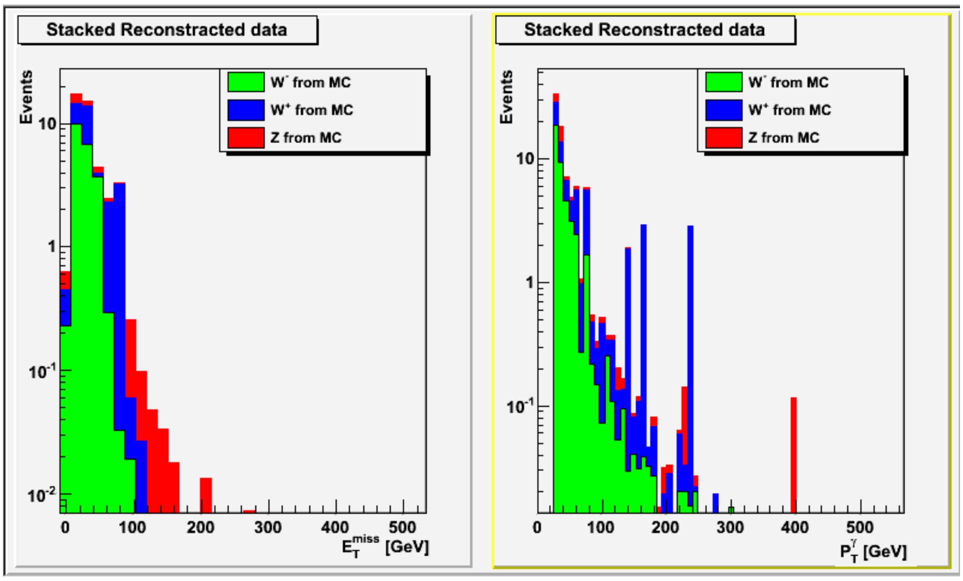


Figure 11: Mixing: shows a (E_T^{miss}) and P_T for W^+, W^- and Z bosons for stacked reconstructed data

In Figure 11 has the combined shape of W and Z .

4. Summary

This work makes an attempt to contribute to searches of SUSY at the LHC with the ATLAS detector. The $\gamma\gamma + E_T^{miss}$ final state is considered. We analyzed data taken at $\sqrt{s} = 7$ TeV corresponding to $1\ fb^{-1}$ and compared several distributions to SUSY GGM predictions. Typicaly, SUSY predicts much harder spectra, hence studied variables provide good separation power. In addition several background sources were studied, in particular W/Z production with the associated electroweak production of two photons. Furthermore, different E_T^{miss} reconstruction algorithms were compared. LocHadTopo shows a better performance than the others.

References

[1] "The ATLAS Collaboration, Search for Diphoton Events with Large Missing Transverse Energy with 36 pb^{-1} of 7 TeV Proton-Proton Collision Data with the ATLAS Detector", CERN-PH-EP-2011-091

[2] G. Bozzi, F. Campanario, M. Rauch and D. Zeppenfeld, "$W^{+/-}\gamma\gamma$ production with leptonic decays at NLO QCD", FTUV-11-0324

[3] G. Bozzi, F. Campanario, M. Rauch and D. Zeppenfeld, "$Z^{+/-}\gamma\gamma$ production with leptonic decays and triple photon production at NLO QCD", FTUV-11-0715

[4] F. Campanario, C. Englert, M. Rauch and D. Zeppenfeld Precise predictions for $W^{+/-}\gamma\gamma + jet$ production at hadron colliders, FTUV-11-0620

[5] The ATLAS Collaboration, "Measurement of $W\gamma$ and $Z\gamma$ production in proton-proton collisions at $\sqrt{s} = 7TeV$ with the ATLAS Detector", CERN-PH-EP-2011-079

Thanks for my supervisors - Wolfgang Ehrenfeld and Martin Wildt!

A. Additional plots

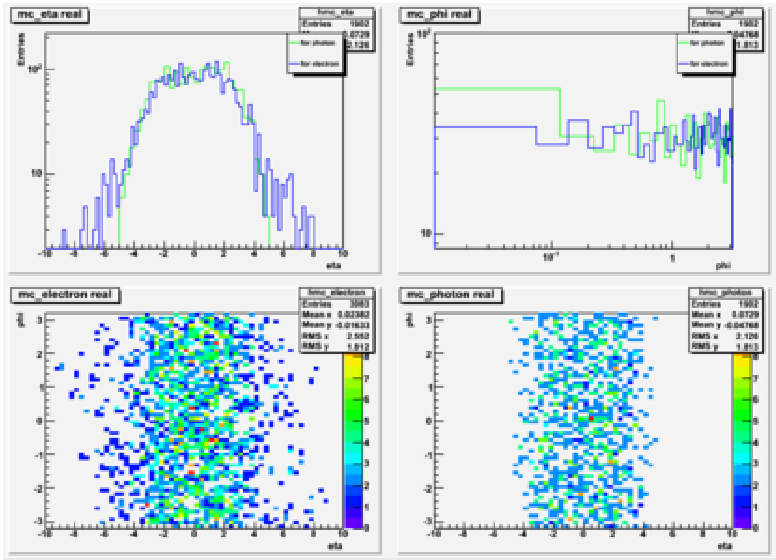


Figure 12: Comparison of photons (blue line) and electrons (blue line) distributions for η and ϕ angles $W\gamma$ productions

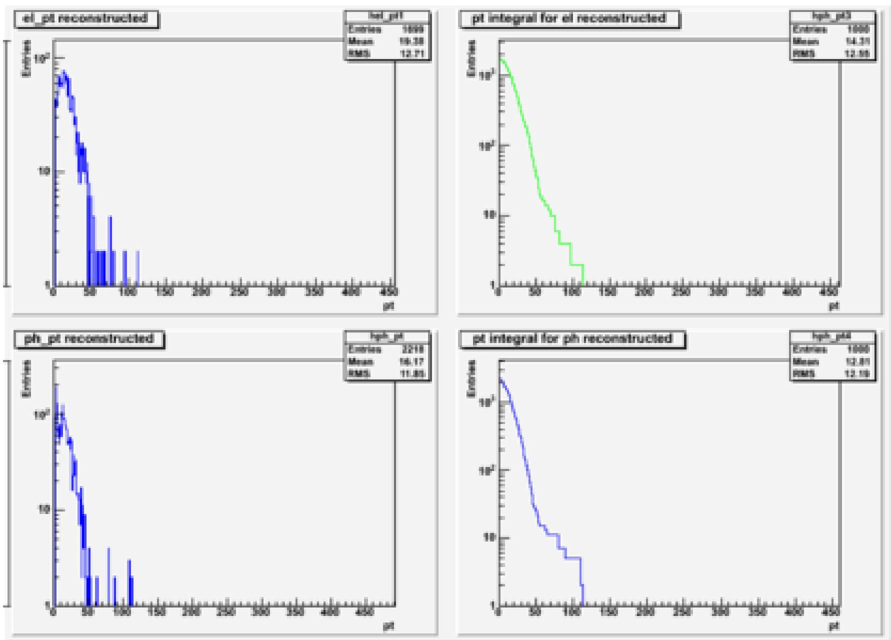


Figure 13: Distributions of $W\gamma$ momentum for η and ϕ angles

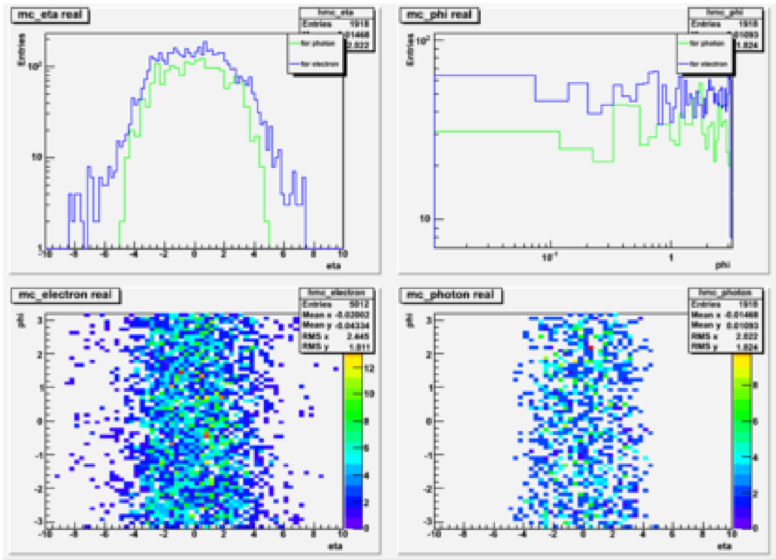


Figure 14: Comparison of photons (blue line) and electrons (blue line) distributions for η and ϕ angles $Z\gamma$ productions

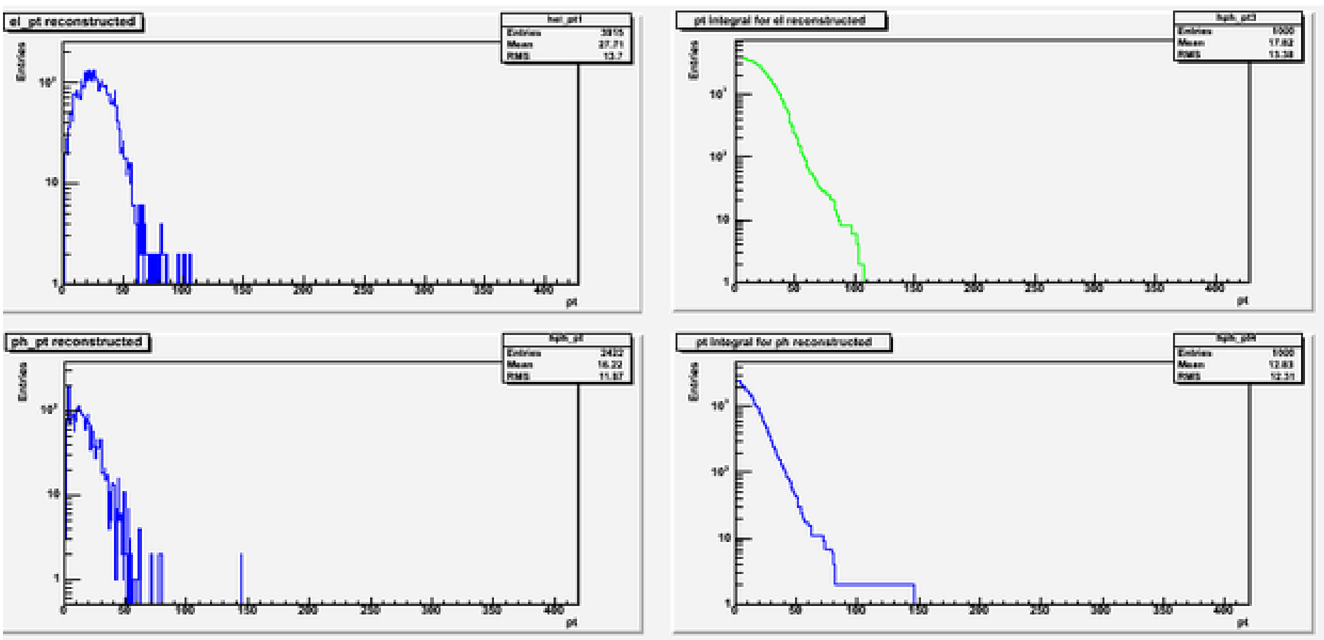


Figure 15: Distributions of $Z\gamma$ momentum for η and ϕ angles